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The Associative Processes of the Guinea Pig. A Study of the Psychical Development of an Animal with a Nervous System Well Medullated at Birth

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THE ASSOCIATIVE PROCESSES OF THE GUINEA PIG. A STUDY OF THE PSYCHICAL DEVELOPMENT OF AN ANIMAL WITH A NERVOUS SYSTEM WELL MEDULLATED AT BIRTH.

By Jessie Allen.

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INTRODUCTION.

In the study of animal psychology the attempt is made to understand in their simplest manifestations the psychical factors entering into reactions to stimuli.

With this in view reactions of all grades of intelligence have been investigated. Two different points of view have given opposing interpretations of the phenomena manifested by the lower animals.

M. BINET[1] has observed the reactions of *Paramecia* to acids and alkalis, and has concluded[2] that an action of adaptation involves spatial perception of the external object, choice between objects and movements of approach or avoidance.

On the other hand, JENNINGS[3] gives a physio-chemical explanation of these same reactions. All the movements of approach and retreat are automatically performed without regard to the "pleasure" or "pain" involved. The mechanism of the

[1] BINET. Psychic Life of Micro-organisms. Transl., *Chicago, Open Court Pub. Co.*, 1889.

[2] P. 61.

[3] H. S. JENNINGS and E. M. MOORE. Studies on Reactions to Stimuli in Unicellular Organisms, VIII. *Amer. Jour. Physiol.*, Vol. VI, 1902.

movements is put into play by the physical or chemical properties of the medium.

The insects exhibit a comparatively complex organization. LUBBOCK and ROMANES attribute a high degree of psychical development to bees, wasps, spiders and ants. Dr. and Mrs. PECKHAM are more conservative, but conclude that there are present memory, spatial perception, and occasional adaptations of means to end.

ALBRECHT BETHE [1] represents the extreme mechanical interpretation of insect activities, believing them to be expressible in terms of immediate sensory stimuli followed by the motor response.

BETHE'S principal opponent is AUGUST FOREL,[2] whose recent work on the ants leads him to conclude "that sensation, perception and association, inference, memory and habit follow in the social insects on the whole the same fundamental laws as in the vertebrates and ourselves. Furthermore, attention is surprisingly developed in insects." These faculties are, however, manifested in a feeble form.

LOEB [3] is inclined to attribute a small amount of intelligence to ants. The question here is whether these animals do or do not have any psychical life. The criterion of intelligence now generally used in experimental work with lower animals is that of educability. LOEB [4] discusses the distribution of the associative processes among the lower animals. When his book was published only tree frogs, among frogs, were known to possess memory.

YERKES,[5] in an extended series of careful experiments, finds that the green frog has associative processes, but that as-

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[1] BETHE. Dürfen wir den Ameisen und Bienen psychische Qualitäten zuschreiben? *Arch. f. d. ges. Physiologie* (PFLÜGER'S), LXX, p. 15, 1898.

[2] FOREL. Ants and Some Other Insects. (Translated by W. M. WHEELER.) *Monist*, Vol. XIV, pp. 33-66, 177-193, 1903-1904.

[3] LOEB. Comparative Physiology of the Brain, 1902, p. 224.

[4] Loc. cit., pp. 219, f.

[5] YERKES. The Instincts, Habits and Reactions of the Frog. *Harvard Psychological Studies*, Vol. I, 1902.

sociations are very slowly acquired. The sensory elements which enter into them are visual, tactual and kinesthetic. YERKES used a simple labyrinth, testing the frog's memory of a path to water; he kept records of time as well as of movements made. A straight path was learned by a process of selection from random movements of those which led to the desired object.

YERKES' work on the crustaceans stands almost alone. The green crab and the crawfish both profit a little by experience and learn simple labyrinth paths [1] BETHE had shown that *Carcinus maenas* could not readily learn to inhibit deep-seated instincts.[2] SPAULDING [3] finds that hermit crabs profit by experience with considerable rapidity when visual and taste sensations may be associated.

Upon comparing the fish, the frog and the turtle [4] YERKES found that the turtle's associations were formed most rapidly, a somewhat complex path being learned in five trials.

Very little other experimental work has been attempted with animals of this grade. TRIPLETT [5] found that perches can remember a glass partition which has been removed from the aquarium. He verified the possibility of teaching pikes to inhibit their habit of devouring minnows (MOEBIUS' experiment).

DELBOEUF [6] has observed lizards in captivity and finds that they differ in disposition and intelligence. They can remember people and places, and they seem to possess the higher emotions as fear, love, jealousy.

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[1] R. M. YERKES and GURRY E. HUGGINS. Habit Formation in the Crawfish. *Harvard Psychological Studies*, Vol. I, 1902.

YERKES. Habit Formation in the Green Crab, *Carcinus granulatus*. *Biological Bulletin*, Vol. III, 1902.

[2] BETHE. Das Centralnervensystem von Carcinus maenas. II Theil, *Arch. f. mikr. Anat.*, Bd. LI, p. 447.

[3] E. G. SPAULDING. Association in Hermit Crabs. *Jour. Comp. Neurol. and Psychol.*, Vol. XIV, p. 49, 1904.

[4] YERKES. Formation of Habits in the Turtle. *Pop. Sci. Mo.*, LVIII, p. 519, 1901.

[5] TRIPLETT. The Educability of the Perch. *Amer. Jour. Psychol.*, Vol. XII, p. 354, 1901.

[6] DELBOEUF. The Affections and Jealousies of Lizards. *Pop. Sci. Mo.*, Vol. L, 1897 and *Revue Scientifique*, Vol. IV, pp. 363-367, 690 and 805.

Animals with complex psychical processes have been studied more extensively than the lowest forms, and the work done here comprises the principal literature in animal psychology. The classical treatises of Principal LLOYD MORGAN are the model and the stimulus for all subsequent investigation. A recent book of his, "Animal Behavior," contains summaries and critical notes of all new literature on animal psychology, and a timely discussion of the current conceptions and hypotheses.

MORGAN, who has worked with chicks especially, finds memory, intelligent adaptations and a considerable discrimination of objects among birds. Besides the numerous researches upon the chick, few other birds have been observed with respect to their psychical processes.

WESLEY MILLS [1] is among the pioneers in the field of experimental psychology. His observations upon a large number of animals, and suggestions concerning the correlation between physical and psychical development, are of especial value as recognizing the problems and methods of most recent investigations.

The employment of the laboratory method of observation and experimentation has led to fruitful results in that, as conditions are known and controllable, explanations of given reactions may be made with a greater degree of assurance.

THORNDIKE has given explicit and clear-cut formulation to the method of experimentation with animals. His free-and-easy psychological terminology, with his desire for a severely scientific interpretation of results, as well as unusual confidence in the meaning of facts observed, stimulate competition, not to say contradiction. My work on the guinea pig has been undertaken from a point of view somewhat similar to that assumed by THORNDIKE; viz., the point of view that the law of parsimony must govern interpretation, and a sufficient number of control experiments must condition every statement made. Reference will be made to specific points of THORNDIKE'S work as occasion arises.

[1] MILLS. The Nature and Development of Animal Intelligence, 1898.

HOBHOUSE, the latest author in the field of animal psychology, has brought keen psychological analysis to bear upon the results of a close experimental study. A dog, a cat and a monkey furnished the best material, while other animals gave corroborative data which, if not taken by HOBHOUSE himself, were controlled and edited by him.

HOBHOUSE is more generous in his estimation of his animals than is THORNDIKE, perhaps because the psychical manifestations for which he looks are clearly defined and characterized in his own mind. An advanced grade of intelligence is not vaguely suggested by the term "free ideas," but is discussed in concrete and comprehensive statements about "the practical judgment," and the "practical idea." By a practical idea is meant "the function which directs action, not necessarily in accord with habit or instinct, to the production of a certain perceptible result. It is further a necessary part of such an idea that it rests on a perceptual basis, and is capable of being brought into relation with another such idea, for example, as means to end." . . . "The correlation of such an idea with a remoter end, I call a practical judgment." [1]

The possession of practical ideas and the ability to make practical judgments HOBHOUSE attributes to dogs, elephants, cats, otter, monkeys and chimpanzees, those being the animals which he examined.

The work of KLINE,[2] followed by that of SMALL,[3] has direct bearing upon the problem of the present investigation. The life habits of the white rat as described by SMALL, present many points of contrast with the habits of the guinea pig. SMALL furnishes a diary of the young white rat, in which its immaturity at birth and subsequent development are described, and later its intellectual development as shown in ability to learn a labyrinth and to solve other simple problems.

In the study of the psychical processes of the guinea pig I have tried to determine:

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[1] HOBHOUSE. Mind in Evolution, p. 207, 1901.

[2] *Amer. Jour. Psychol.*, Vol. X, p. 276, 1898.

[3] *Amer. Jour. Psychol.*, Vol. XI, p. 80, 1899.

(1) What processes are characteristic of the adult guinea pig.

(2) How these processes develop from birth to maturity.

More specifically, it was undertaken to show what problems could be learned, at what age the most complex problems were first learned (thus affording an indication of psychical maturity), and what elements contributed to the learning of the problem. As far as possible, the purpose was to gain an insight into the psychical processes of the guinea pig.

The problem and method of work were suggested to me by Professor ANGELL and Professor DONALDSON. They have constantly defined the inquiry, and indicated the general bearing of particular observations.

The investigation is a complement to that made by Dr. WATSON in this laboratory, and to his work[1] there will be constant reference; before the close there will be a comparison of our results with deductions from them. I am under obligation to Dr. WATSON for constant suggestions and help, as well as for the method of work.[2]

However, it is quite essential, both from a psychological and a neurological point of view, that this work should be undertaken. The white rat is born very immature, its eyes are not yet open, it is naked, its nervous system is entirely unmedullated. The guinea pig, a rodent closely related to the white rat is, on the other hand, born very mature. It is quite able to take care of itself at birth, has full possession of all its senses, is well covered with hair, and, as will be seen, its nervous system is almost completely medullated. The psychical immaturity of the white rat is such as would be expected from its physical immaturity; whereas the guinea pig has a comparatively complete mental equipment at birth.

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[1] JOHN B. WATSON. Animal Education, *Chicago*, 1903.

[2] Loc. cit., pp. 5-6.

Part I. The Associative Processes of the Guinea Pig.

From the literature we can glean very little concerning guinea pigs in the feral state. Originally from South America, they were brought to Europe for pets soon after the discovery of the new world. They were first named, pictured and described by Gesner in his Natural History Folio.[1] Gesner knew it as "indische Kaninchen," or "indische Schweinchen," indicating the current belief that its home was a part of Asia. Many other names were applied to it in the first descriptions. Alfred Brehm calls it "Huf-pfotler" (hoof- or claw-footed).

The pets brought to England were smooth, short-haired and slender, and are now known as English cavies, or common guinea pigs. When they were interbred with different varieties in the London Zoölogical Garden, and with the French cavy, other breeds were produced, and there are now four varieties recognized by fanciers—the English, Abyssinian, Angora and Peruvian cavies.[2]

The variety used in this investigation was the English cavy, though individuals of all varieties have been under observation without giving evidence of any characteristic differences in habits or intelligence. In one case a series of experiments was made with a solid red Peruvian (probably not of pure stock, however), and numerous minor experiments were made with other varieties. No difference was found between them and the common guinea pig.

I. Habits of Guinea Pigs.

So far as we have been able to observe, all or nearly all the activities of guinea pigs may be termed instinctive, since they are present from birth and hence are carried out without previous training or experience.[3] Certain characteristic modes of

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[1] Gesner. Appendix historiae quadrupedum viviparorum Conradi Gesneri Tigurini, *Zurich*, 1554.

[2] Mrs. Stanley Walker Mirick, "All About Cavies," published by *American Stockkeeper*, *Boston*, 1901.

[3] Lloyd Morgan. Animal Behavior, pp. 63-71, 1902.

behavior which develop shortly after birth with the perfection of the muscular coördination, may be termed "deferred characteristics."

Individual differences in habitual behavior of the guinea pig may be considered either as intelligent adaptations, or as accidental variations; probably when these slight modifications are analysed, the more tenable view will be that the majority of the individual characteristics are variations. Individual characteristics show themselves in rapidity of movement, habitual activity, tameness, adaptability to changing situations, and in such habits as climbing, gritting the teeth, squealing, etc.

Certain characteristics become modified and altered as time goes on. One group of guinea pigs at first chuckled a great deal, the cause of which I am unable to state. Apparently the noise was made by the rapid gritting of the teeth. One individual would begin it and immediately every guinea pig in the room would take it up and continue for half a minute or more. Within three months this habit was discontinued almost entirely.

In its diet the guinea pig resembles the rabbit. It is voracious and will gnaw almost anything in the vegetable kingdom. Its foods in the laboratory are carrots, oats, hay, grass, lettuce and parsnips. It gnaws constantly, the wire, the floor, the partion, anything within reach. In this, too, it resembles the rabbit. Its manner of eating and of searching for food would lead one to the conclusion that it is a grazing animal in its natural habitat.

The guinea pig bears constantly, and is quite prolific in confinement. The average number in a litter is two, though litters of one or three occur frequently. The period of gestation is from 65 to 69 days, and the young are weaned about the end of the second week. Growth is retarded by birth for 2 to 5 days. From 5 days to 12 months there is a steady increase in weight. The age of sexual maturity is extremely variable, but seems to be about four months.[1]

[1] MINOT. Senescence and Rejuvenation First Paper: On the Weight of Guinea Pigs. *Jour. of Physiol.*, Vol. XII, p. 97, 1891.

A description of the development of the habits in the young, on a subsequent page, will, I think, show that most of the habitual reactions of the guinea pig are of the instinctive type. Fear of specific objects is probably not instinctive; reaction to warning cries seems to be acquired from the mother after birth; and domestication leads to the modification of some sounds, and probably, to a certain extent, to a partial inhibition of running and jumping activities.

The guinea pig is a social animal. When several are put into a cage they huddle together in one corner, and when they are alone in contiguous cages with wire partitions between them, they are generally to be seen as close together as the wire will permit.

As a rule there seemed to be greater activity in the dark than in the light, more freedom of movement being present. Several times I noticed when the light was turned out the animal would immediately begin to eat. This observation is confirmed by a remark of ERNST VON FRIEDL, who, in speaking of the guinea pigs' natural habits, says "They lie down in the long, dry grass where they live, and keep concealed most of the day. They are more night than day animals."[1] The possible differences in activity in the dark as compared with light has been borne in mind during experimentation.

The note of warning is a sharp cry. Usually it is uttered when any dark object passes the window. Once or twice I have known it to be given when a shrill whistle sounded near by. Many visual stimuli will call it forth. At first my reaching my hand to turn on the electric light overhead caused the note of alarm—not of fear. The cry produced instant quiet throughout the room. I have not heard it responded to except by a mother with young who utters a very low "burr-r-r" to them and thus quiets them. The cry of fear is loud and shrill, seeming to indicate nothing of caution or concealment, while the alarm call is softer and more deliberately uttered. Guinea pigs

[1] FRIEDL. Zur Familiens- und Lebens-Geschichte des Meerschweinchens, Cavia cobaya, Marcgrave. *Zoologische Garten*, April, 1889.

do not seem to understand the significance of the warning note until they are three or four days old. Now that the guinea pigs are quite thoroughly tamed, both the note of warning and expressions of fear are rarely observed.

Other sounds uttered are series of shrill squeals and cries indicative of hunger. When I enter the room, if it is near feeding time, the little fellows remind me of their presence. When I approach the basket of carrots, and particularly when the sound of cutting reaches their ears, their squeals are urgent and vociferous. Each individual can be recognized by its voice, as there is great individual variation.

If general conversation is ever maintained amongst the guinea pigs at their social gatherings, it consists only in an occasional "ghrr-r-hr," a sort of gutteral aspirate sound like a note of perfect content with life. There is a characteristic tone uttered by the male to attract the attention of the female. This is the "coycobaya," which is said to have furnished the South American natives with their name for the animal (Cobaya, Spanish, Cuy or Coy). The female responds with a low, musical "r-rerp-rerp."

If the guinea pig is surprised, or if anything of doubtful character attracts the attention of the whole group, a "burr-r" is uttered, and there is instant quiet throughout the room. If the experimenter keeps perfectly still the guinea pigs remain noiseless for several minutes. If, on the other hand, the customary laboratory occupations go on, confidence is restored and they return to their gnawing or eating.

Observations of the young would lead to the conclusion that fear is not present at birth. No motor expression of fear could be produced by moving objects, or by any noise, or by touching, pushing or striking. The only reactions to sound that seem to be indicative of fear are those produced by a shrill whistle as described later. It must be remembered that laboratory conditions are unfavorable for the awakening of fear in those animals whose only enemies are creatures of the grass and copse.

The hiding instincts of the guinea pigs remind us distinctly

of a time when a quick retreat would bring them under the friendly cover of a tuft of grass or a little hillock. If the experimenter attempts to catch them they dodge under hay or any cover at hand. No cover being forthcoming, the spot next chosen for safety is a corner of the cage where they huddle up and watch proceedings. Unfortunately laboratory cages were not made to harmonize with their particular color effects, so that the desired result of being invisible is not accomplished. In order to study this point a cage was fitted up simulating the scenery of their grassy South American home. To obtain the best conditions the light was rendered dim by a high board fence, while sticks, stones and mounds of earth completed the realism. It is thought, from observations of both young and old under these conditions, that they rely for escape, not so much on protective coloration, as upon hiding under grass in little inequalities of the ground. However, the English variety, which is presumably nearer the original than any other in the laboratory, is particularly harmonious in color with surrounding grassy mounds.

When undisturbed, the guinea pigs wander contentedly around and nibble grass, but let them suspect that an enemy may spring upon them and they approach their food only by making a bold dash out of their retreat, and drag the food back into a dark corner. In the experimental work this was almost invariably the way food was seized from the boxes, even when the environment was uniformly lighted, so that there could have been no immediate advantage in snatching the food backward a few inches. At first my own movements attracted much attention from certain individuals. This has to be taken into account in the first series of experiments, as will be noted. However, when the strangeness has worn off and the work becomes habitual this factor is greatly reduced, if not entirely eliminated.[1]

At first perfect quietness in the room is apt to delay reaction with all the individuals upon which I have worked. After

[1] THORNDIKE has discussed the fact that dogs pay more attention to the experimenter and less to the experiment than do cats. Animal Intelligence, p. 38.

the food is reached only one or two bites may be taken, and then even if hungry, the guinea pig remains quiet. But if I rattle paper or my keys during that time, or talk to it, it begins to chew and continues to eat.

The movements of the guinea pig are not well adapted to climbing or jumping. As a rule it has a strong dislike to jumping off a board to the floor of the cage. It will look around and try every means of climbing down, and when compelled to jump does so very awkwardly. On the other hand, it will run off the edge of the table if left alone, and fall to the floor. If it happens to have approached the edge very slowly it will not fall; but generally it seems to have not the least idea that the plane surface upon which it runs does not extend over the rest of the universe. In this too, however, there is individal variation. It may be due to the inadequacy of vision. The suggestion has been made by Dr. WATSON that the difference between the rat and the guinea pig in this respect may be due to a difference in the clinging power of the claws, and in the sensitiveness of the feet to touch. At least it may be safely concluded that the guinea pig has no sixth sense[1] which warns it when there is danger of falling.

Observations leads me to believe that vision in the guinea pig serves primarily for orientation, and for detecting the presence of moving objects. I have not been able to formulate experiments to determine this point definitely. All experiments with colored cards, colored light, and distinctively visual stimuli have given ambiguous, not to say negative results.

The monocular vision which the guinea pig necessarily possesses on account of the position of the eyes and the configuration of the nose, undoubtedly prevents the clear differentiation of objects at close range. There is no demonstrable

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[1] SMALL discusses the phenomenon as a "sense of support." He says that all young land animals show hesitation when they approach a void (*Amer. Jour. Psychol.*, Vol. XI, p. 80). YERKES finds that there is a difference in the space perceptions of tortoises, land species showing more hesitation when they approach a void than water species. (Space Perception of Tortoises. *Jour. Comp. Neurol. and Psychol.*, Vol. XIV, 1904).

fovea [1] or other modified area of the retina. It seems the most probable hypothesis that vision serves, as said before, for general orientation, and for the organization of a situation in which a stimulating odor forms one of the important elements. That the one reinforces the other, and that both are utilized in ordinary life processes is indicated by the comparison between reactions to a problem in ordinary daylight, and reactions to the same problem in the dark where vision is practically useless. The complete elimination of the food odor, and the employment of only a visual stimulus of food have thus far given negative results.

II. Characteristics of the Developing Guinea Pig.

A. Description of the Young Guinea Pig at Birth.

As stated above, the guinea pig at birth is well covered with hair, its eyes are open, it can hear, smell, touch and taste. Movement is not coördinated, and slight muscular weakness is apparent. Frequently when the little creature stops running one hind leg is left sprawling behind the body. The head is proportionally much larger than that of the adult. There is no fear of an approaching object, such as the hand in front of the eyes, nor of persons. But a shrill squeal like that of a rat causes first an instantaneous jump, and then a twitching of the muscles: This is a momentary reaction ; it may be followed by hiding under the mother, but there seems to be no "panic," nor rapidity of movement as if to escape. While this may be an initial stage of fear, still the attitude of the little fellow is quite different from that of the frightened adult.

A carrot or other vegetable food produces no motor reaction toward it, though before the first day is over the small guinea pig will eat grass, bread and milk, and nibble at a carrot.

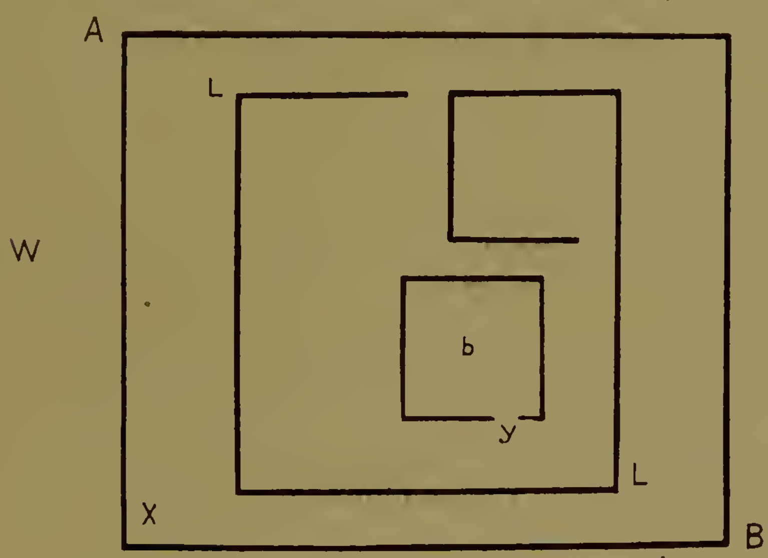
Test I. Is the mother a specific stimulus for her young?

Observation had indicated that carrot or other vegetable food furnished no stimulus toward which the very young guinea

[1] Preparations of the guinea pig's eye were kindly made and examined by Dr. J. R. SLONAKER, in this laboratory, and the above statement is made upon his authority.

pig would react. Therefore I desired to find whether the mother herself could furnish a motive for a solution of a problem. In order to do that the following preliminary experiment was made:

I put guinea pigs two hours old in the experimental cage while the mother was placed in a wire box in plain sight. They could reach her by going to the small opening in the wire. She seemed not to be a stimulus, and there was no attempt to reach her. The little ones' independence of their mother is emphasized by the fact that they ran about quite freely and contentedly for an hour or more away from her. On her part she paid no attention to them, and only in rare cases did any mother gnaw and attempt to reach her young family, even though the little ones had been away from her for an hour or more. In one case I removed a guinea pig five hours old from the mother and left it three hours. At that time the mother was put in an experimental cage within a simple wire labyrinth (Text-fig. 1).



Text-figure 1. Labyrinth I.

A B is the experimental cage used throughout all the experiments. The floor is of wood, and the sides of small wire. It is 3½ ft. long by 3 ft. wide, and usually rests upon two stools or a table at such a level that the light from the windows, *W*, gives uniform illumination over the cage.

The labyrinth, *L L*, is of light weight wire, ½ in. mesh. The wire box, *b*, is 10 by 10 by 10 in., thus being perfectly comfortable for a large guinea pig. It is entered by a small entrance, *y*, just large enough for a little guinea pig.

The little ones were placed at *x*, 24 inches from the opening *y*. The mother was plainly visible through the wire, and could probably have been smelt by a sensitive nose. But she seemed to provide no stimulus leading to definite purposive activity. The young guinea pig gnawed a little at the wire ; probably an instinctive reaction, for there seemed to be no recognition of the proximity of the mother, i. e., no association was yet set up between the sight of the mother in this environment and the satisfaction of hunger, if hunger were present. Another female was put in the place of the mother, and the attitude of the young remained unchanged. When the young one was replaced in its home cage, it immediately found its mother and began to suck. The other female was substituted for the mother and the little one attempted to suck her.

At 38 hours the guinea pig squeal in its infantile form is fully developed. Movements are almost as well coördinated as in the adult and there is great activity. The movements about the cage are similar to those of the adult while hunting food. The fore feet creep forward, the bright eyes are on the alert, the belly is flattened to the ground, and the hind part of the body is dragged forward.

The peculiar movement of the guinea pig, so characteristic of the first three weeks of existence, begins to appear on the second day. I can attempt only a description of the movement; what its significance may be, why it arises and disappears as it does, and what form it assumes in the adult I do not know definitely. The guinea pig will run for a few steps, then give a sudden jump forward or in some other direction, then run and jump again. The jump may not be preceded by a running movement; it may be forward close to the ground, or shorter and somewhat more in the air. The jump is so sudden and violent as to be quite startling. It reminds one of the playfulness of a little calf kicking its heels. For some days this is almost the only method of locomotion. It is probably a sign of superfluous activity conspicuous in young animals ; and the sudden zig-zags of the course may have facilitated escape at a time when movement could not be inhibited.

At the age of 62 hours evidence of the mother's acting as a specific stimulus is given by the act of the guinea pig in making a real attempt to get to her through the wires of the box. With many individuals such definite recognition of the mother occurs even later.

Development varies greatly in individuals. It seems true without doubt that the larger the guinea pig at birth the more active it is, and the sooner it reaches full coördination and the ability to solve problems presented to it (problems which depend upon activity).

From MINOT'S observations[1] it was concluded that the length of gestation is shorter the larger the litter, and the shorter the gestation the smaller the litter. Therefore it is probable that variation in activity and development is a question of maturity, since the small animals are in the large litters. In a litter of two, one pig is apt to be somewhat smaller than the other, and to be a few hours behind it in the appearance of characteristics indicative of progressive stages of maturity, e. g., the jerky running movement which seems to be a good objective criterion of development.

In spite of their social instincts I have never seen the little guinea pigs play together. There is never anything like mock combats among the young such as form a striking feature of rats' play.[2]

B. Experimental Work.

Introduction.

In the experimental work the kinds of problem to be given the guinea pigs were determined by careful preliminary observation of their natural habits and tendencies. No problem should be given to an animal which involves the inhibition of

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[1] Loc. cit., p. 113.

[2] This small amount of play activity offers a suggestion in favor of the theory of play described in MORGAN'S Animal Behavior, p. 315. If play is a preparation for the serious defensive and offensive work of adult life, the animal which never makes an attack and has no defence except to run away, could not be expected to spend its youth in sham battles.

a deep-seated instinct.[1] Those experiments in which the time element (the interval between stimulus and response) is of importance should not be foreign to the natural tendencies; all innate proclivities should be seized upon and, so far as possible, should be utilized. The stimuli depended upon with the guinea pig were hunger and desire for company. The former, since it could be carefully controlled and kept a constant factor, was used almost entirely.

It was found that problems whose solution involved activity were solved most readily, while those which involved ingenuity were not solved at all. By ingenuity is meant a very simple process, the putting of two and two together. A paw or a nose may be used to attain an object when other methods have failed. Within narrow limits the guinea pig is very active, many of his movements being made at random. It can select a few movements which have been successful and omit those which have not, so that a path is learned merely by a proper direction of activity. But there is no adaptation of movement to a complication in the problem offered which would involve even a simple new coördination. The absence of all power of adaptation is the absence of all ingenuity.

The guinea pig is a grazing animal, as has been mentioned; it neither digs nor climbs for its food, but runs about. It scarcely ever pulls or pushes obstacles violently, and its gnawing is not adapted to getting into a box. A guinea pig will gnaw for five minutes at a freely swinging door without happening to give it a hard enough push to open it. The gentle swinging of the door back and forth seemed to suggest nothing. All attempts made thus far to give problems similar to those solved by cats and dogs (by THORNDIKE, HOBHOUSE and others) were unsuccessful, in the case of the adult as well as the young.

Even though extremely hungry the little fellow will get discouraged after finding that all the methods he knows fail to reach the food, and he will sit down in a corner of the cage and remain there. At one time I left my brightest guinea pig six

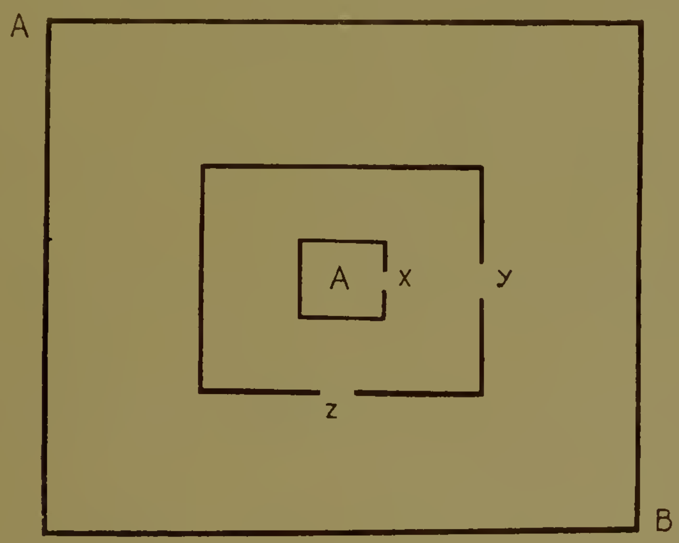
[1] YERKES and HUGGINS. Habit Formation in the Crawfish. *Harvard Psychological Studies*, Vol. I, 1902.

hours on a simple problem of ingenuity,[1] and returned to find it in the same position. Another guinea pig was left all night to solve a problem[2] but failed.

The problems which could be most successfully solved were simple boxes with doors swinging from the top so that they could be easily pushed open; and various forms of labyrinth. It will be seen that the prerequisite for solution of such problems is activity and not ingenuity. The mentality required was only recollection of the path leading to the food sufficiently distinct to modify successive reactions. The associations which might be formed were controlled as carefully as could be, and will be mentioned under the various experiments.

Test II. Recalling a simple path.

Simple problems of finding the way were given to the



Text-figure 2.

[1] The door of a wire box was to be pulled open by a string running over a pulley and hanging free outside about the level of the guinea pig's nose.

[2] The problem was to walk up an inclined plane, push open a wooden door hung at the side, pass through a short wooden passage to a wire door also hung at the side, and pushing that open, to walk down another inclined plane to food in the next cage. The food was visible and could be smelt through the wire partition between the two cages.

young guinea pig. The apparatus used was a wire box (6 by 6 in.). The apparatus was placed in the experimental cage (described under Text-fig. 1), so that there was never any crowding or cramped quarters for the animals. In many of the experiments where the path chosen was of importance, and direction of turning and number of random movements were to be observed, the floor of the experimental cage was covered with glazed paper which had been smoked some days before. Preliminary experiments showed that the guinea pig was in no way disturbed by any contact, noise or odor of the paper, and never observed it any more than the usual floor of the cage.

A guinea pig, age 1 day, was placed at *A* within the wire box which had a swinging door, *x*. The larger box had two simple openings at *y* and *z*. The mother was placed outside in the experimental cage. The wires and experimental cage had been carefully freed from all odors by scalding. It will be remembered that at the age of one day spontaneous movement is very slight, and though the smoked paper shows some movement within *A*, the guinea pig did not find its way out. It saw its mother for it usually faced her as she wandered about the cage.

Age, 2 days. Conditions and apparatus the same. Random movements were directed toward finding a way out, and the first solution of the problem was made in 12 minutes.

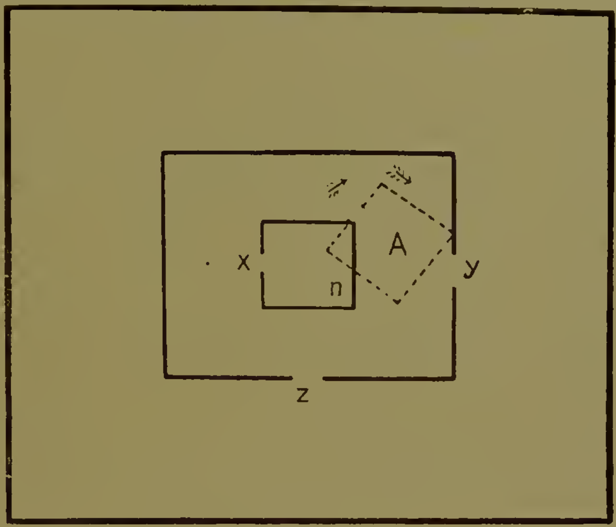
It was replaced. For .25 min. it sat perfectly still with back to the opening and to the mother. Then it turned, and in .083 min. had found her. This is the first proof of the formation of an association.

Upon being replaced for the third time, it found the first opening, but the mother had moved and it went directly toward her. Finding the wire in the way, it went to the second opening, *y*, as usual. Time, .75 min. Few random movements here occurred.

Test III. Alteration in habit.

The experiment was then modified, and the swinging door turned from the opening.

When put inside, the guinea pig immediately pushed the wire at the point where the swinging door had been before, and so pushed the wire box against the other wire (as in the dotted lines, Text-fig. 3), thus cutting off one path to the second opening.



Text-figure 3.

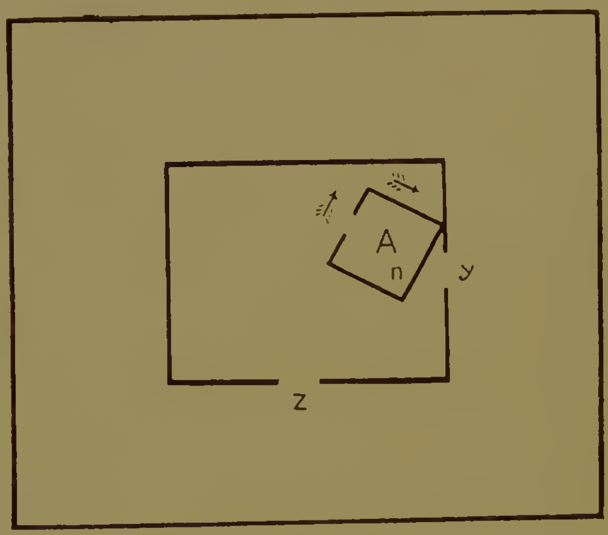
It still scratched and gnawed at the old place, but failing to get out, set out on an exploring tour. In 1.33 min. it had found the door. It then ran around the box in the direction of the arrows to get out at *y*, but found itself shut off there. It began to look again, and in .58 min. had found the opening at *z*. Total time, 2.083 min.

Replaced in A (Text-fig. 4).

The guinea pig sat perfectly still for 1.91 min. Then it turned around and pushed gently at the point where the door had been in the first problem. Not finding the wire to swing easily, it turned directly back and pushed the door open without any random movements. Time, 2.16 min. Then it again went in the direction of the arrows, and found its way closed; then turned and immediately found the opening at *z*. Total time, 2.5 min. The smoked paper showed a minimum of random movements.

Results: At the age of two days there is unquestionable evidence of recollection. It will be noticed that the random movements made in the last trial are almost identical with those

of the other trials, except that minor random movements have been eliminated, and only the principal movements chosen for emphasis. The guinea pig had not succeeded in getting out by



Text-figure 4.

going in the direction of the arrows, yet this same path was chosen the second time, it having been one of the major movements which, as a group, were previously successful.

Test IV. Does the odor of the previous path furnish the stimulus?

Age, 3 days. There is a possibility that the odor of the path just taken might serve as immediate indication of the path to be chosen again. Therefore the reaction would be mechanical, i. e., in terms of immediate stimulus and response, not of recollection.

In order to test this the odor of previous trips was eliminated by thorough scalding of the wire cages and boxes to be used. The wire cages were then set upon glass instead of smoked paper. The apparatus was set up as in Text-fig. 2.

Time for guinea pig to find his way out, .33 min. No random movements. The apparatus was then set up as in Text-fig 4.

Time. .83 min., the path being the one chosen on the previous day, i. e., including the major random movements.

Upon a second trial of the problem at this time (the wires,

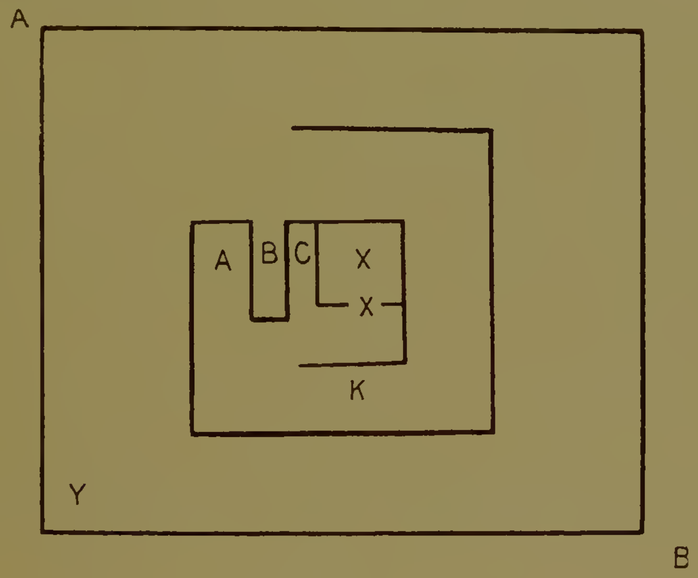
etc., being washed) the time was cut down to .33 min. All random movements were eliminated except a little push at *n*; the route chosen was direct.

One important conclusion, I think, is that the path was not learned by tracking, i. e., that smell did not enter into the formation of the association.

The slow disappearance of random movements suggests that kinesthetic sensations are an important factor in learning a path, though that they are not the only factor is shown by the elimination of unessential movements, indicating that something beside mere sequence of sensations enters into the association.

Test V. Complexity of associations.

The most difficult labyrinth experiment which was to be presented to the adult was now presented to the three days old, in order to determine how complex a path could be learned.



Text-figure 5.

As usual the labyrinth was made entirely of wire. *A*, *B*, *C* are alleys from which there is no exit. The entrance to the wire box, *X*, is very small and is open.

Care was taken to have the whole cage free from any odor. The mother was placed at *X* and the little one at *Y*.

Time for finding the mother in the first trial was 5.166 min.

In the second trial the time was reduced 2 min. There were few random movements, and no blind alleys were entered.

The question arose, How far did the previous experiments with the guinea pig aid it in learning the more complex path?

A guinea pig from the same litter that had never been used for experiment was now tested. It was smaller and not quite so mature as the first one used. When placed in the labyrinth, conditions as for I, it wandered about 45 minutes without finding its way in. This seemed merely chance, as its activity was sufficient to make it wander all over the cage. It paid no attention to the mother, nor had the first one, so far as I could judge, since finding her seemed a matter of accident the first time.[1] I simplified the labyrinth by removing the part directly in front of the entrance (*K*); the mother was found in 33 min., probably by chance.

The apparatus was washed and replaced as in the first instance (Text-fig. 5). Time, 3.166 min.

Repeated. Time, .416 min. All random movements were eliminated. The recollection of the pathway chosen persisted, since experiments on the next day (age, 4 days) with the different individuals showed few random movements and short time reactions.

Close observation of all individuals, as to manner of turning and of moving about, indicates that kinesthetic sensations[1] are a controlling factor in the learning and retention of a path to food. A movement once made and "stamped in" by the pleasure incident to the obtaining of food quickly becomes automatic.

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[1] It is hard to know when the young are actually trying to reach the mother (i. e., when she is a specific stimulus). I found definite indication that she furnished a stimulus for the young at the age of 62 hours (p. 309); but even later many of them at times would apparently pay no attention to her, and would not go to her when in the same box.

[1] YERKES has rightly insisted upon the importance of the kinesthetic sensations with animals of a simple psychical organization. (Instincts, Habits and Reactions of the Frog. *Harvard Psychological Studies*, Vol. I).

The experiments were repeated on four different groups of young during an interval of five months. The smaller ones were always a little later in their solution of the problems than their larger brothers, because their movements were neither so rapid nor so numerous. When the way was once found they remembered as accurately as the others.

C. Summary of Work With Young.

1. The guinea pig at birth is physically mature with the exception of slight muscular weakness and inaccurate coordination.

2. That no experimental indications of associative processes were obtained at the age of one day seems to be due to the small amount of activity at that time.

3. All individuals examined learned a simple path to their mother at the age of two days.

4. The most complex problem solved at all was solved at the age of three days, and the recognition of it persisted. There was no indication of increase in complexity of psychical processes after the third day. The problems learned between one and three days depended upon increasing activity, and not upon increasing intelligence.

5. For the reasons previously given, it is probable that kinesthetic sensations are of paramount importance in determining the recollection of a path.

III. Experiments With the Adult.

It was found that if the guinea pig had been without food for twenty-four hours, the odor and sight of food were sufficient to induce continuous movement for a considerable length of time, and if mere activity could solve the problem it was most quickly solved under these conditious.

Objections have been made by MILLS[1] and by MORGAN[2] that experiments upon animals which have been starved beforehand were rendered invalid by the abnormal conditions. In my experimental work on the guinea pig I have not been igno-

[1] *Psychological Review*, Vol. VI, p. 265.

[2] *Animal Behavior*, p. 151.

rant of these objections, and so far as they are legitimate, they will hold against my work. But I do not think the presence of hunger can be considered as vitiating the experiments. The desire for food is a natural condition, and can scarcely be regarded as an abnormal stimulus in any case. The guinea pig is a phlegmatic animal, insusceptible to considerable variations of temperature and food, as one would naturally suppose from its thick covering of fur, and its ready accumulation of fat upon which it may live. When beginning my experiments even with animals perfectly tame, the problem was to get them to attend to the food in the problem box. The incentive to obtain the food had to be rendered quite strong. My custom was to feed the guinea pigs once a day, about five o'clock in the afternoon; enough hay and oats were left in the cage to last all night and well into the next morning. Those animals with which I intended to experiment were left unfed one day and experimented with at about 2:30 p. m. the next day, when they were fed as usual. This was found to produce the requisite degree of hunger to gain attention to the problem, though there was nothing like the "utter hunger" of THORNDIKE's cats and dogs. In no case was there "frantic activity" indicative of an abnormal state. Previous observations had demonstrated that hunger any less intense did not succeed in eliminating mere curious exploration, or even quiescence in one corner of the cage.

Upon first introducing the guinea pigs into the laboratory they were wild and easily frightened, and disturbed by my presence, or by any unusual sound or movement. An attempt was made to carry on the experiments in their customary room, but the sight of the other guinea pigs, and when that was shut off, their sound proved a disturbing factor. For that reason the animals to be experimented upon were removed to another room.

A few weeks of persistent and continuous petting, handling and training finally accustomed them to the presence of the experimenter, and gradually the problem came to absorb attention to the neglect of any outside element. Animals born in the laboratory did not have to pass through this preliminary

training. It was found that less disturbance was produced with them by working in the animal room, as all the guinea pigs were now accustomed to the presence of the experimenter, and did not alter their daily routine. Later all experiments were carried on in the animal room without any complications arising.

Test VI. Preliminary.

January 24. I took adult guinea pigs from their cages to another room where conditions of noise, etc., could be governed. Owing to their extreme timidity and fear of handling they did not recover from the removal sufficiently to give any reactions. It then became necessary to tame them, to accustom them to their new surroundings, and to acquaint them with the first apparatus to be used. For this purpose each animal was brought to the experimental room and left in the wire cage several hours daily. Each guinea pig was also handled and petted as much as possible.

January 29. They had become used to the petting and apparatus, and had practically learned the simple problem to be taught them first. They had not solved the problem, but had been taught.

The method of teaching was as follows: When first placed in the cage they remained quiescent in one corner. I placed food very near them, and soon they made a dash for it. Gradually I removed the food farther away, but they were afraid to enter the box. When they became accustomed to my hand I held the food toward them and tolled them to the box. After a few trials they learned to get into the box for the food.

This record of the manner of teaching an animal has interest because of THORNDIKE's observations upon the same subject. He concludes[1] from a questionnaire to animal trainers, that "None of these [the trainers] would naturally start to teach a trick by putting the animal through the motions. . . I see no reason for modifying our dogma that animals cannot learn without the impulse."

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[1] *Psychological Review*, Mon. Suppl., Vol. II, p. 72.

In his experimental work THORNDIKE emphasizes the method of learning as that of a selection from a large number of random movements of certain movements which are stamped in by the pleasure of success. I believe, however, that a guinea pig may be taught a trick without waiting for selection from among random movements. What was done was to "control the impulse," and by impulse we mean the amount and direction of muscular innervation.

On the previous Saturday the guinea pigs had remained almost motionless for two hours after being put into the experimental cage. On Thursday the problem had been learned.

A typical series of reactions is given, after the problem has been learned. Until that time the difficulties of fright, strangeness, etc., already mentioned, rendered any time record or other measure wholely meaningless.

The apparatus used was a wire box, 10 by 10 by 10 in., with a wire door hung from the top so as to swing freely in and out Care was taken that nothing should distinguish the door from the rest of the box. In every case the guinea pig has had no food for 24 hours. The food stimulus used is always carrots freshly cut, which has a strong odor; also it is in plain sight in the wire box. The animal is adult, and in this example is of the solid red Peruvian variety, though mixed with the solid red English.

Jan. 29.[1]	Time.
Door to food box open	.5 min.
Door to food box open	.083 min.
Door to food box open	.066 min.
Door closed	.066 min.
Door closed	.66 min.
Jan. 30.	
Door open	.5 min.
Door open	.25 min.
Door open	.25 min.
Door closed	.25 min.
Door closed	.15 min.
Door closed	.133 min.
Jan. 31.	
Door open	.415 min.
Door closed	.183 min.

[1] It will be observed that throughout the work more than one trial was given during an experiment. At any one time only a little food was given.

The reactions took place almost mechanically. The box seemed to be the thing-to-be-run-into. It was always in the same position. In this way, whether the door was open or closed seemed to make no difference; it was pushed open rapidly when the position of the entrance became an habitual one, and the reaction was not perceptibly lengthened.

From the preliminary test it was concluded that the guinea pig would react to a stimulus under laboratory conditions. The elements entering into the situation were (a) the sight and odor of food; (b) the sight of the box, and association of the general environment with food; (c) the association of a certain series of kinesthetic sensations with the satisfaction of hunger.

Test VII. Distinction of stimuli.

An attempt was made to determine what the stimulus was which induced the reaction to the problem.

The food was covered with a glass dish, and care was taken to eliminate all possible odor from the box. There seemed to be no shyness of the glass dish as it was treated with indifference when left in the cage. Nevertheless, the possibility that fear might not have been observed though present, must be borne in mind.

Jan. 31.	Time.
1.	.5 min.
2.	.75 min.
3.	.083 min.
4.	.083 min.

The first time I did not give any food when the guinea pig got into the box. The effect of this disappointment is seen in the second reaction; at that time I gave food, then removed it quickly. The same was done in the third reaction.

At this point in the experiment it seems certain that a smell stimulus is not necessary to produce the reaction after the situation has been learned.

In order to determine if possible what stimulus is the strongest a choice experiment was introduced.

A dish was arranged in a wire box with the carrot in plain sight but covered with glass. Into another and similar wire

box carrots were placed, lightly covered with sawdust. A third wire box was empty.

Visual	Blank	Olfactory
.25 min.		
.23 min.		1.25 min.

Two wire cages made on the same plan as that first learned but smaller were used. One was empty, the other had a visual stimulus as before. The new boxes were first learned in the ordinary way, by placing the food in one in an open dish. It was first entered in 1.083 min., and the next time in .483 min. The food was then covered with a glass dish and placed in the other cage. The cages were about 1 ½ ft. apart, and exactly alike. The guinea pig was placed 3 ft. away, facing them. Every time the box with food was entered the guinea pig was given a bite of food, and the food was then transferred to the second cage. During the time of rearranging the apparatus the guinea pig was always removed from the experimental cage.

Visual stimulus.

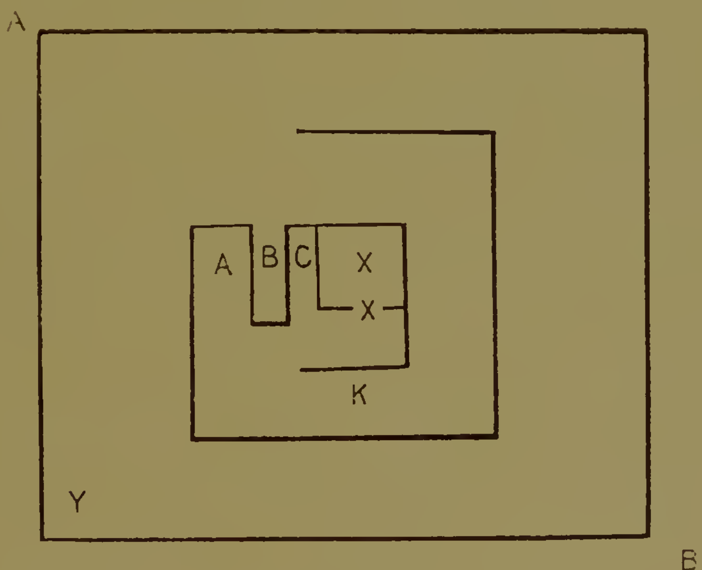
Box with food.		Box without food.
		.25 min.
		.066 min.
.55 min.		
		.399 min.
.25 min.		
.2 min.		
	Feb. 5.	
		.166 min.
		.15 min.
		.1 min.
		.33 min.
		.187 min.
		.066 min.
.313 min.		
.313 min.		
.264 min.		
	Feb. 6.	
.5 min.		
		.66 min.
.1 min.		
		.264 min.
.083 min.		
		.083 min.
		.066 min.

From this experiment we conclude that no choice is present. That is, no immediate discrimination is made between the two boxes. This leads to the inference that the food in itself furnishes no stimulus. But when placed in a given situation the guinea pig reacts to the environment as a whole.

Test VIII. Learning a labyrinth.

The next step in the experiment was to complicate the path to the food, thus to find how quickly a more complex path would be learned.

For this purpose a wire labyrinth was constructed (Text-fig. 6).



Text-figure 6.

The apparatus is described on page 315. The cage was floored with smoked paper. The guinea pig was placed at *Y*.

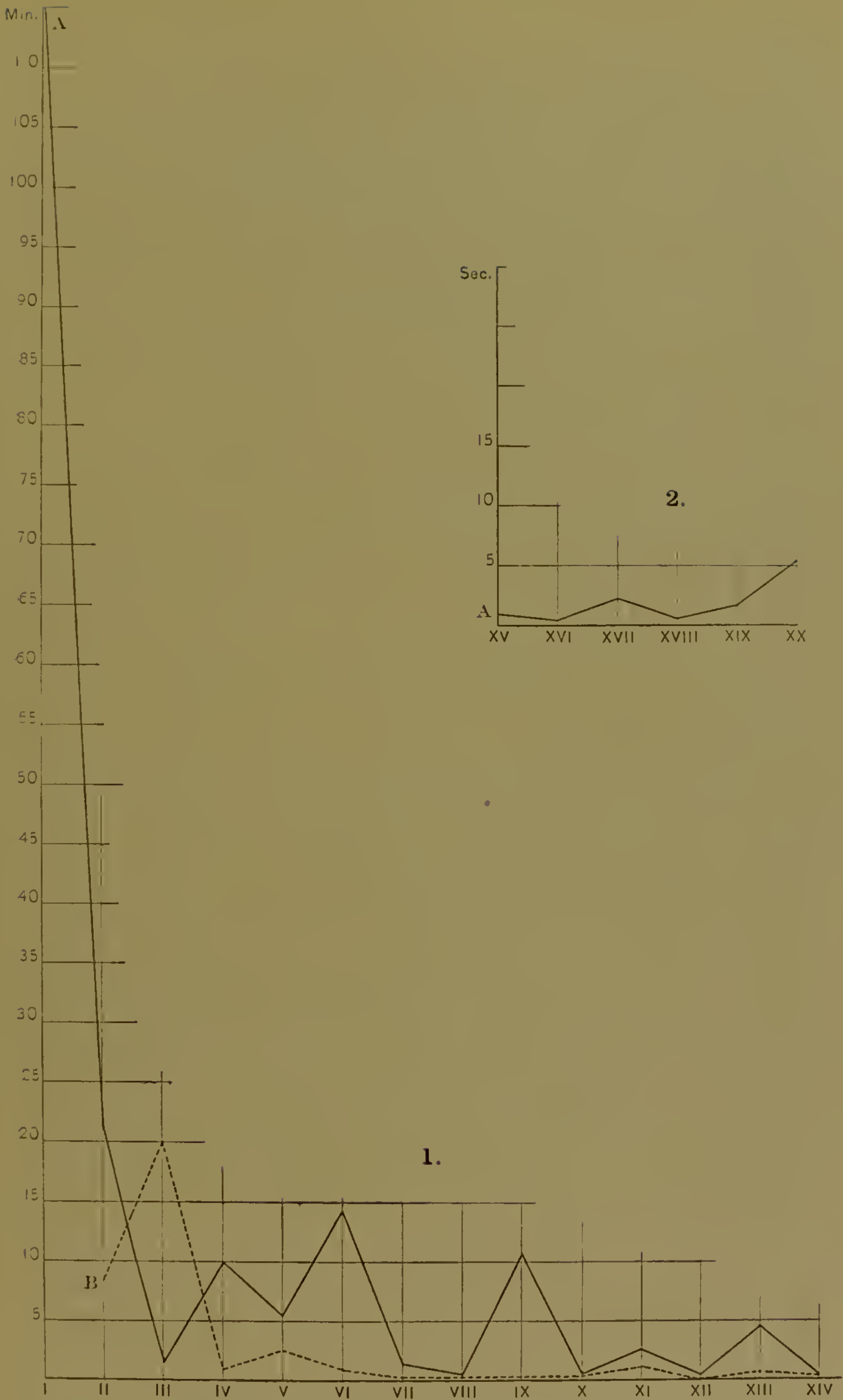
A typical series of reactions will be given.

Feb. 12. The animal explores the cage, but is perfectly passive most of the time. Found the food in 1 hr. 55 min.

Feb. 13	Time 31 min.
Feb. 14	1.462 min.
Feb. 15	9.75 min.
Feb. 16	5.5 min.
Feb. 20	15 min.
Repeated	1.33 min.
Feb. 25	.5 min.
Repeated	.25 min.
Feb. 26	2.616 min.
Repeated	.83 min.
Repeated	.483 min.
Feb. 27	4.516 min.
Repeated	.55 min.
Feb. 28.	For some reason did not go in. Left 22.5 min.
Mar. 1	.366 min.
Repeated	.2 min.
Mar. 3	2.316 min.
Repeated	.513 min.
Repeated	1.75 min.
Mar. 5	6 min.

In this problem there was choice of two directions to be taken to the entrance. The guinea pig was always put down in a fixed spot, namely at *Y*. It could go to the right or left. As a matter of fact, some individuals learned one way and some the other, and the direction taken was not always the same with the same individual. As a rule, when the problem had been learned the blind alleys were omitted. Attempts to gnaw through the wires at various points were abandoned after the first few times, when another method had proved more successful.

The six guinea pigs which learned this problem, three of which were used at the same time as the example given, were remarkably uniform in their results. There was no sufficiently important variation to deserve remark. The variations which did occur were to be accounted for by difference in tameness, or by some chance noise producing fear and thus requiring time for recovery. Two curves of the time required are here given. (Text-fig. 7.) The time in minutes is indicated on the ordinate, while the divisions of the abscissa represents the numbers of the trials.



1. Curve showing the time of learning the labyrinth, two individuals, A & B
2. Curve of persistence of the habit. 63 days later.

Text-figure 7.

The paths taken by each individual were preserved by the smoked paper. The most interesting points which the smoked paper shows are two: (1) The number of motions on the part of the adult as compared with the young is much smaller, and are less free. (2) There is a tendency on the part of the adult to keep as close as possible to the wire.

The early movements are different from the adult in kind as well as in number and freedom; the jumping movements mentioned previously are soon lost.

The adult guinea pigs have a peculiar and characteristic method of sneaking across an open space, or of stealing up on food and snatching it back into an imagined retreat. Domestication partially removes this fear of being seen, and the movement does not develop early or strongly in the laboratory young. I think it probable that the "agora-phobia" is an acquired characteristic, or an instinct which, in accordance with JAMES' "law of transitoriness," has lacked fixation by habit, and so has faded away.[1]

The typical series of reactions to the labyrinth was completed March 5. On April 20 the same guinea pig was given the same problem, having been free from experiment during the interval. Conditions of hunger were the same as those previously obtaining.

Time required for the solution, 1 min. Some time was lost in exploring the cage, but after once entering the labyrinth only .3 min. elapsed before the food was found. Each turn was made accurately, showing perfect familiarity with the pathway. Two blind passages were barely entered.

April 22, a day having been omitted to preserve the food conditions constant, the times were (1) .33 min. (2) .33 min.

April 24, time, .166 min.

Therefore we conclude from the elimination of random movements and from the short time required, that the recollection of the problem persists at least 48 days, undiminished in its efficiency.

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[1] Principles of Psychology, Vol. II, pp. 398-402

On July 27, 63 days later, the same test was repeated with the same animal. Time required, .33 min. Conditions were the same as before. The apparatus was freshly washed, and smoked paper used to show the movements. The only difference was that the guinea pig was taken at the usual feeding time, and it had not been handled for two months.

July 27	Time, .33 min.
July 28	1.33 min.
July 30	.2 min.
July 31	.415 min.
Aug. 3	.166 min.

At this time this and several other of the experiments were repeated on other individuals, and the memory in every case was almost perfect.

Conclusions from the labyrinth experiment.

I. The guinea pig can learn a complex path to food.

II. The time curve for learning is very abrupt for the adult, and for any one individual is also irregular. It tends, however, to reach a minimum at which point it is, after a few trials, nearly constant. In the labyrinth used this minimum will be observed to be .166 min.

III. The curve for elimination of random movements follows very closely the time curve, as random movements necessarily increase the time required.

IV. There are two kinds of random movements: (1) Those made in attempt to reach the food, as biting the wire, running into blind alleys; (2) those of superfluous activity or curiosity, as exploring the cage, running about, and jumping. When the guinea pig seemed in too playful a mood to attend to business, it was a sign that it was not hungry, and therefore conditions were not uniform.

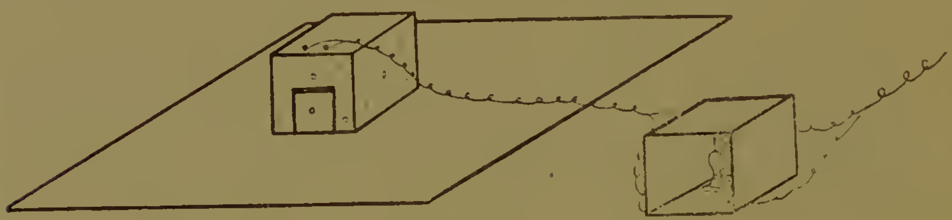
Test IX. Learning without the aid of vision.

Granted that the guinea pig can learn a complex path, the problem arose, What sense elements contribute to this result? What does the guinea pig remember?

The guinea pig may orient itself by means of vision, by

means of smell, or by kinesthetic impressions. It will be remembered that when the simple wire box was placed before the guinea pig, it ran in exactly as it was accustomed to do, although no food was inside. The box itself was then the stimulus, as being associated with food.

To determine how quickly the odor of food alone could set up the association, a series of experiments was designed, in which the visual factor was eliminated.



Text-figure 8.

The apparatus used in this test was a simple wooden box, 6½ by 6½ by 6½ inches, with numerous small holes bored in it (Text-fig. 8) A door was swung by hinges at the top A copper spring inside the door made contact with a plate in the top of the box when the door was pushed open. Connection was made with an electric light in a dark box entirely outside the experimental cage. The experimental cage was covered with a black cloth frame, and all experiments were performed at night, so that no light should be present. Noises and other accidental disturbances were thus diminished.

In the first series of experiments it was possible, after the reaction had been made and the light turned on, for a faint glow to penetrate the cloth covering of the experimental cage. At a later time these results were verified in the dark room where no light could enter, and the arc connected with the apparatus was so arranged that no illumination of the room was possible.

The typical series given was taken from an adult guinea pig about nine months old, of the smooth English variety. It had not been used before for any experimental work, and therefore the first thing that had to be done was to tame it, and ac-

custom it to being brought upstairs. As usual, the quickest way seemed to be to associate the experience with food. On Feb. 12 it was taken to the dark room at the usual feeding time and put in the experimental cage. After having been left there about half an hour it was returned to the guinea pig room and fed lightly.

Feb. 13. It was taken to the experimental cage, food having previously been placed there. In 5 min. the food was found and was pulled to one side of the cage to be eaten.

Feb. 15. The food was put in a wire box, but was not found. The guinea pig was now becoming tame, and behaved naturally when removed to the experimental room. Fright had disappeared.

Feb. 16. The electric food-box was used with the door open. The food was not visible in the dark, and the door was left open in order that the slight grating of the hinges, the noise of the contact of the spring with the plate, and the touch of the door itself might not frighten the timid animal. The time was recorded from the moment of placing the guinea pig in the experimental cage until the sound of pulling out the food was heard. (When the door to the box was closed the appearance of the electric light gave a more accurate time limit.) The food was found, seemingly accidentally, in 2.264 min.

Feb. 17. Animal very active. Food not found.

Feb. 18.	Door to electric box open.	Time .05 min.
	Door to electric box open.	Time 25 min
	Door to electric box open.	Time 1.083 min.
	Door to electric box open.	Time 5.581 min.[1]
Feb. 22.	Door open.	Time 1.85 min.
Feb. 24.	Door open.	Time 11.88 min.
	Repeated.	Time .1 min.
	Door closed.	Time .43 min.
	Door closed.	Time .35 min.
Feb. 25.	Door closed.	Time 2.913 min.
	Door closed.	Time .528 min.
	Door closed.	Time .43 min.
Feb. 26.	Door closed.	Time 4.726 min.
	Door closed.	Time .783 min.

Feb. 27. Rattling of windows in the wind frightened the guinea pig, and therefore no reactions.

Feb. 28.	Door closed.	Time .83 min.
Mar. 1.	Door closed.	Time .89 min.
Mar. 2.	Door closed.	Time .25 min.
Mar. 3.	Door closed.	Time 1.363 min.
	Door closed.	Time 1.783 min.
	Door closed.	Time 1.783 min.
Mar. 5.	Door closed.	Time .183 min.
	Door closed.	Time 2.33 min.

[1] This increase in time was probably due to two things; (a) not so hungry

The results of this series of experiments when compared with a similar series taken in the light are these: (1) The range of variation in reaction-time is greater in the dark than in the light; (2) A longer time is required to form a definite habit of entering the cage for food; (3) The average time required, even omitting the excessively long periods, is longer than that required for the analogous experiment in the light. This is true in spite of the greater activity of the animal in the dark and the greater freedom with which exploration is made; (4) It follows, therefore, that the number of random movements is much greater in the dark than in the light. This the smoked paper shows to be almost invariably the case.

Conclusions from the four tests.

In those tests in which only a visual stimulus of food was permitted in a situation not previously associated with food, there was no attempt to obtain the food; it apparently did not attract attention. Other experiments, particularly the choice experiment of test VII, gave negative results as to the efficiency of a visual stimulus when not reinforced by other stimuli.

From the sixth and seventh tests it was concluded that, after a situation is once connected with food, it is reacted to as a whole with the appropriate movements An odor stimulus of food is then not a part of the situation essential to the reaction.

From the eighth test we found that the situation might be considerably complicated without diminishing the appropriateness of the reaction. A situation which presents difficulties of the kind which the animal would meet in its natural environment, is rapidly learned and reacted to almost automatically.

The ninth test has shown that vision is an important element in learning the problem, but cannot be the only element, since the problem was learned without it, though more slowly.

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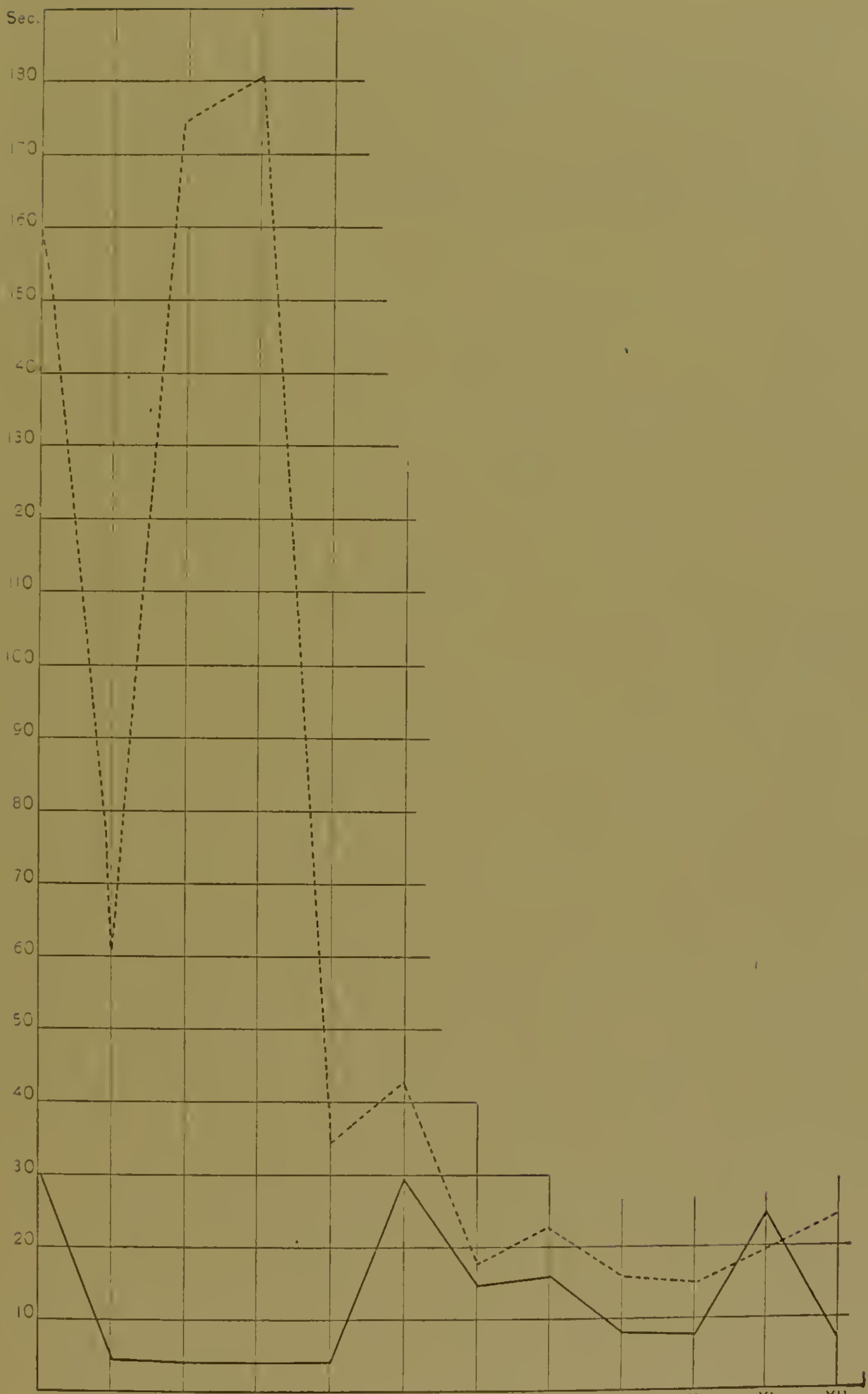
after eating the bite or two allowed at each entrance, (b) a little fright and discouragement from being repeatedly removed from food. The lengthened time of reaction was often noticed if the experiments were repeated several times in succession, and therefore too frequent repetition was hereafter avoided.



Curve of learning simple food box. —— in the dark.
----- in the light.

Text-figure 9.

The paths taken throughout all the experiments by the guinea pigs, their customary accuracy in turning corners, and the general precision of their movements after the problem is learned give unmistakable evidence of the great importance of kinesthetic sensations in the recollection of the path.

Test X. Preference for the dark.

A series of experiments was now tried which did not lead to anything definite, and hence will be only mentioned.

Observation had not indicated any preference of the guinea pigs for the dark side of the cages, or for remaining under cover except when frightened, but the fact that always in the evening they are most active suggested that there might be a preference for dark passages.

A large galvanized iron box was divided into a light and a dark compartment, and an opening was so arranged that the partition in the box divided it also into halves. Food was placed in equal amounts at the distant ends of both compartments, and the guinea pigs were placed outside in the experimental cage. That tracking or any odor other than the food might not complicate the situation, the box and cage were always carefully washed after each trial.

The first few records with two of the four animals tried indicated a slight preference for the dark side; but all the rest of the trials, forty or more, showed the choices of the light side to be equal to those of the dark side.[1]

The conclusion, therefore, was that for this particular kind of test there was no preference for the dark.

Green, blue and red glass covers were substituted first for the white glass, and then for the black glass covering the respective compartments, but in a large number of trials no preference was indicated.

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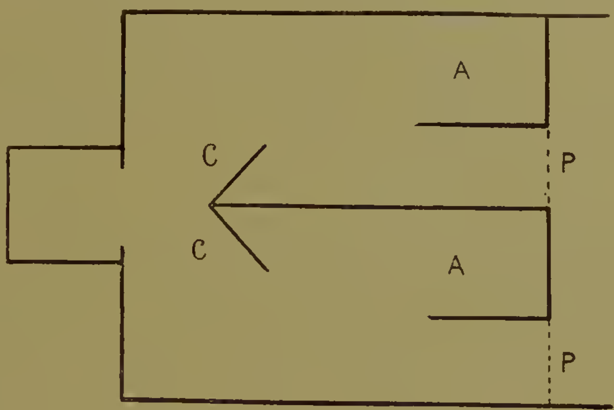
[1] Dr. WATSON found with the white rat no preference for dark passages. Animal Education, p. 56.

Test XI. Means of Orientation.

It was hoped to determine more accurately the signs which the guinea pig uses to learn its way.



Text-figure 10.

At *c c* cards of different colors could be slipped into a frame. *A A* are blind alleys, and *p p* removable partitions of glass. *X* is the food.

Preliminary experiments were made to see whether the guinea pig tends to form a habit of going in a certain direction for food. If any preference were shown it was for the right hand path (Text-fig. 10.) A glass partition was then put at *p* on the left path. The right path was soon learned. The cards (white and red) at *c c* were interchanged. Not a particle of difference was noticeable in the action of the guinea pig. When the partition was put to the right side the guinea pig learned the left path in three trials, with numerous random movements.

Two guinea pigs were tested a large number of times in this way. For one a green card always indicated the side of the partition, and when the partition was changed the card was changed. With the other guinea pig several colors were tried. They almost invariably chose the path which had led to the food at the previous trial, regardless of the cards. Two guinea pigs, tried without any cards, did the same thing.

The apparatus was made of wire and glass, so that I could wash it after each trial and thus do away with any possible path odor.

I believe my series of experiments too limited to draw any conclusions as to the effect of any particular sign in the field of vision. My experiments lasted two months and were performed every other day, two trials being given each day.

It will be noticed that the experiment is borrowed from YERKES.[1] In a long series of experiments on frogs he came to the conclusion that the frog observes colored cards and modifies its actions accordingly.

Test XII. Efficiency of contact stimuli for following a path.

It was suggested by Mr. G. H. MEAD that the reactions of the guinea pig might be direct responses to immediate contact stimuli, and that a distant stimulus, e. g., a recollection of the path, was not responsible for the reaction. While it is difficult for me to conceive how random movements could be eliminated and a path followed accurately after two months, if the performance were merely in terms of direct response to immediate stimulus, nevertheless I welcomed the suggestion of testing the part played by contact sensations in the learning and recollection of the labyrinth.

The labyrinth of text-figure 6 was taken into the dark room. I used three animals which had never before been in the labyrinth but which were perfectly tame. As the conditions for all were the same, and this number was used only to obviate any error arising from individual variation (which proved to be unimportant) I shall give a typical series from one animal.

The labyrinth was first learned in the light (electric). Carrot, as usual, was the food stimulus. Smoked paper was not put on the floor. The tameness of the animals prevented long delays as in the first experiments, and their activity was like that in their home cages.

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[1] *Harvard Psychological Studies*, Vol. I, pp. 589-594.

Aug. 10.	Time 1 min.	Was evidently accidental.
Aug. 12.	Time 3.166 min.	
Aug. 13.	Time .83 min.	
Aug. 14.	Time .21 min.	
Aug. 15.	Time .783 min.	
Aug. 16.	Time 1.166 min.	
Aug. 17.	Time 2.33 min.	
Repeated.	Time .264 min.	
Repeated.	Time 1.33 min.	
Aug. 18.	Time .913 min.	
Repeated.	Time .264 min.	

I then substituted the wooden box used in test IV (text-fig. 8) for the wire food box, and turned out the light, but a loud noise in the next room frightened the guinea pig, so that the experiment was discontinued

Aug. 19. The room is again made perfectly dark, the wooden electric box in the labyrinth. Time 3 min.

The guinea pig knocked against the wire at *K'* (text-fig. 6) which seems to suggest inaccuracy of contact sensations.

Repeated. Time 2 min.

The times are rather longer than in the light. I replaced the wire box in the labyrinth and arranged the lighting wire so that when the swinging door was pushed open it would make the current. The contact conditions were then exactly the same as those obtaining in the light.

Repeated. Time 2 min.

The wire *K'* was pushed down, which had never happened in the light, and the guinea pig walked over it to get in.

Aug. 20.	Time 1 min.
Repeated.	Time 1.25 min.
Aug. 21.	Time 1.25 min.
Repeated.	Time 2.5 min.
Repeated.	Time 1.83 min.

The wire labyrinth was now learned since there were few random movements, and though the time was longer than in the light, there was the accuracy of movement showing familiarity with the turns to be made.

To test whether the successive steps of the path were recollected through immediate contact stimuli, it was necessary to change the character of the contact and leave all the other conditions the same. Only the first reaction after such a change

would have significance. Should the recollection of the path be due to successive tactual sensations we would anticipate confusion and a lengthening of the reaction time when the contact stimuli have been changed.

A labyrinth similar to the wire labyrinth in its proportions was constructed of cardboard. (The advantage of the darkness is now apparent, since the visual conditions were not modified. The cardboard used had been purposely left in the experimental cage when the latter was not in use, but even then the odor conditions may have been slightly different.) Holes were made in the cardboard food-box, and the door was swung from the top as usual. A black cloth was spread over the floor of the experimental cage to change still more the tactual conditions. The electric wire was attached to the door to make contact when the door should be pushed open. The guinea pig was then brought to the dark room.

Aug. 22. Time 1.75 min.

In order to test whether this time was accidental another trial was given.

Repeated. Time .75 min.

One would hesitate to lay much stress on the guinea pig's sense of touch in comparison, e. g., with that of the white rat, because of the difference in the vibrissae. While the white rat's vibrissae are long, motile, and extremely sensitive, those of the guinea pig are shorter, coarse, and are not continually in use. The hair of the guinea pig serves for a covering rather than for a sense organ. I made a number of experiments by touching various parts of guinea pigs which were quite wild. If great precaution be taken that the guinea pig shall see no movement, its hair can be touched lightly at any accessible spot on the body behind the head without causing a reaction. I never succeeded in touching any part of the face without being seen.

We have seen that there was no lengthening in the reaction time when the contact conditions are changed, therefore we infer that the path through a labyrinth is not learned solely, or even largely, in terms of tactual sensations

Conclusions from tests X, XI and XII.

I. There are no indications that the guinea pig prefers a dark passage, or any particular color of light.

II. A colored object in the visual field, if it be stationary, apparently has no significance in the recollection of the path to food.

III. Alterations in the tactual conditions of the environment, other conditions being as far as possible unchanged, cause neither increase in reaction time nor confusion of movement.

IV. Since neither odor, vision nor touch is alone of paramount importance, and since, when light is shut out, the odor of a previous path being at the same time impossible and tactual conditions being new, the recollection of a path remains accurate and unconfused, we conclude that the factors of greatest importance in recalling a path are the sensations of running and turning, and of other movements gone through during a previous trial. The innervations of these movements are no doubt especially significant.

V. Hearing, seeing, touching and smelling are all of them important in the reactions of the guinea pig.

Summary of Work with the Adult.

1. The guinea pig can learn problems the solution of which depends upon activity, but not those requiring ingenuity.

2. The path to food is found first by accident, but when it is once found, random movements are rapidly dropped out and the reaction becomes almost automatic, providing no outside disturbing factors enter.

3. Odor of food is a stimulus which induces reaction, but the time required to learn the path from an odor stimulus alone is longer than from stimuli affecting all the sense organs.

4. Experiments to determine the efficiency of a visual stimulus alone were negative.

5. Kinesthetic sensations are of great importance in the recollection of a path.

IV. Development of the Guinea Pig Compared with that of the White Rat.

Guinea Pig.	White Rat.
Weight: Varies greatly at birth. Av., female, 70.8 gr.; male, 70.1; Adult, f., 800.5; m., 776.9 gr.[1]	Av., 5 gr. at birth. Adult, female 200; male, 250 gr.
Senses: Eye functions fully at birth.	Opens 16 to 17 days.
Ear functions at birth.	Functions fully after 13th day.
Touch never very sensitive.	Sensitive around the mouth, otherwise dull.
Smell perfect at birth.	Sensitive at birth.
Taste perfect at birth.	Present, but no differentiation between pleasant and unpleasant.
Body: Thoroughly covered with fur; complete muscular development except the hind legs.	Naked, ill-developed, immature in form and musculature.
Nervous system: practically completely medullated.	No medullation at birth.
Spontaneous movements not numerous but strong at birth. On second day movements very numerous.	Movement very slight and weak at birth, and does not attain vigor until fifth day.
Coördination: imperfect for first three days but perfect thereafter.	The few movements attempted are coördinated, and after learning to crawl (from 4th day) coördination rapidly increased.
Random movements: increase in number from 2 to 8 days. About constant throughout maturity.	Increase in number and vigor from 4th to 60th or 70th day.
Psychical Development.	
Instincts: almost fully functioning at birth.	Instinctive reactions are characteristic of life up to 12th day.
Memory: proved to be present at second day. Perfect at 3 days.	Develops soon after 10th day. Perfect at 19 days.
Psychical maturity: 3rd day.	23 to 27 days.

The data for the white rat are derived from the records of Small[2] and Watson.[3]

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[1] Minot. Senescence and Rejuvenation, *Journ. Physiol.*, Vol. XII, p. 131.

[2] *Amer. Jour. Psychol.*, Vol. XI, pp. 80-100.

[3] Animal Education, *Chicago*, 1903.

V. *The Psychic Life of the Guinea Pig Compared with that of the White Rat.*

The Use of the Senses.—With the white rat, in the search for food, the sense of smell is paramount.[1] Smell is by far the most necessary sense in the life economy. This sense does not play nearly so important a part with the guinea pig. It is an efficient sensation, but is apparently neither a definite nor a strong incitement to reaction.

As with the guinea pig, so with the rat, vision seems to function mainly for orientation. But the rapidity with which moving objects, especially those which cast a shadow, are seen indicates that the guinea pig uses his sense of sight to detect the approach of dangerous objects.

The noises most quickly reacted to are those indications of danger and other signals made by the guinea pigs themselves; and sounds associated with feeding time.

The most important senses with the guinea pig are the kinesthetic. We can almost say that the guinea pig does the greater part of its remembering in kinesthetic terms. WATSON suggests that the memory of a path by young rats is motor.[2] How prominent a feature of rat life motor reactions are has not been discovered by any experiments yet carried out.

Memory Processes.—WATSON found that memory processes of the white rat are not present before the twelfth day (p. 63), but before the twenty-second day they have reached a development sufficient to enable the solution of problems conditioned chiefly upon activity (p. 73). Psychical maturity is reached at from twenty-three to twenty-seven days of age (p. 83).

The experiments upon which these conclusions are based are: (a) A simple labyrinth used to test the earliest appearance of memory of a path to the mother; (b) other more complex labyrinths, in the solution of which activity was mainly involved, with memory of the path chosen; (c) boxes with different methods of opening, involving a memory of more complex movements than merely those of following a path to food.

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[1] Animal Education, p. 84.

[2] Loc. cit., p. 85, foot-note.

The obtaining of the food may have first occurred accidentally and the successful movements have been rapidly selected for retention by being "stamped in," or by the elimination of random movements not pleasurably emphasized ; or an intelligent factor may have entered into the selection of movements once found to produce the desired result of obtaining food. At any rate, it was found that "No form of problem which the adult rat is capable of solving presents insurmountable difficulties to the rat of twenty-three days of age" (p. 84).

The guinea pig stands in complete contrast to the white rat. Though no experimental records of memory were obtained from the guinea pig during its first day, a simple path was learned upon the second day, and upon the third day the most complex problem was solved, being a complicated labyrinth.

No experiments were made with the rat to determine how early a complicated labyrinth could be learned, but WATSON'S rats solved a simple labyrinth at nineteen days.

When the guinea pig has found his way through a labyrinth he has reached the end of his psychical powers. He cannot pull a latch nor push a bolt, he will not depress an inclined plane, he will not chew a string nor stamp his foot. All the ingenuity which the white rat acquires after he has solved the labyrinth is a *terra incognita* to the guinea pig who thus pays the penalty of his early maturity.

The experience of the white rat extends to strange combinations of wires and springs, and all the delightful surprises revealed by secret doors. But when the guinea pig has turned the proper number of corners his dinner must be waiting for him or he does not get it.

The rat at three days is just learning to crawl, has never seen an object and remembers nothing. The guinea pig at that age has triumphantly recalled a complex path, at the end of which he sits eating his well-deserved carrot.

At twenty-three days the rat is lifting latches neatly, and forming what HOBHOUSE calls "practical judgments" as to the value of an inclined plane in a situation at the center of which

is his food—a desired thing, an end. The guinea pig is still wearing out the floor of the same labyrinth.

Were we to anticipate our later work we would suggest that the significant contrasting features in the two animals are their nervous systems. In the one a mature nervous system is accompanied by psychical maturity; in the other, neural immaturity permits great psychical development.

PART II. THE CENTRAL NERVOUS SYSTEM OF THE GUINEA PIG.

Introduction.

The investigation of the central nervous system of the guinea pig has for its purpose the description of the conditions present at birth, and the changes in the medullation of fibers between birth and maturity.

When an adequate notion of the nervous system and its growth changes has been obtained, it will be desirable to correlate these facts with the physical and psychical responses described in a previous part of this work. In view of the corresponding investigation of the white rat, a comparison will be made between the nervous system of the guinea pig and that of the white rat.

The progressive medullation of the central nervous system has been correlated by many authors with the progressive acquisition of function.[1] Nevertheless, WATSON has shown in the case of the white rat [2] that both the peripheral and the central nervous systems are entirely without medullated fibers at birth, while many impulses are at that time transmitted to the central system and there coördinated; and that complex associative processes are present before the medullation of those areas which may mediate associations in the cortex. Furthermore,

[1] A summary of the previous work on medullation will be found on pages 108 to 111 of Animal Education. The discussion of FLECHSIG'S work is on pages 6 and 7, and a criticism of his wholesale correlations between function and medullation on pages 121-122.

[2] Animal Education, p. 117.

the complexity in the psychical life of the white rat is wholly out of proportion to the very few tangential fibers to be found in the cortex.

Technique.

The guinea pigs used for histological study were of the common English variety. From a large number of nervous systems hardened and stained the following ages were selected for examination :

Birth,	male,	108	grams,	used for illustration.
3 hrs.,	"	101.5	"	
1 day,	"	84.5	"	
2 days,	female	83	"	
3 days,	"	106	"	
3.5 days,	"	87	"	
6 days,	"	70	"	
11 days,	"	176.4	"	
30 days,	"	250.41	"	used for illustration.
Adult,	male,	617.9	"	used for illustration.

Each guinea pig chosen for study was in good physical condition, the wide range of weight indicated in the table being within the bounds of normal individual variation. Most of those animals used in the psychological experiments were afterward killed for examination.

The central nervous system was exposed and hardened *in situ* in MÜLLER's fluid. The tissue was kept in the dark during the hardening process, which required about fifty days for the small animals, and from sixty to seventy days for the adults. The sections were embedded in celloidin, ten grades being used,[1] and were cut 21 μ thick. They were stained according to the PAL-WEIGERT haematoxylin method, modified slightly to obtain the best results from this particular tissue. In detail the modified method is as follows: After cutting sections in 70% alcohol they were run to distilled water, then mordanted in MÜLLER's fluid 24 hours, at a temperature of 36 to 40° C. Washed thoroughly in distilled water, 2 to 4 hrs. Fresh WEIGERT's haematoxylin (cold) was poured over them, and they

[1] HARDESTY: Neurological Technique, p. 69.

were placed in a temperature of 40° C, 24 hrs. Washed well in numerous changes of tap water about 12 hrs. In differentiating no attempt was made to complete the permanganate decolorization at once, but the sections were allowed to remain in the permanganate from 15-25 secs., washed in distilled water, then placed in the oxalic-acid-sulphite mixture for several minutes, or until differentiation ceased to be apparent. Then they were washed in distilled water, replaced in permanganate a short time and the former process repeated. The best results were obtained when the tissues were carried back and forth three or four times. Subsequent washing in tap water was very thorough.

The sections of the spinal cord were made at the level of (1) the sixth cervical nerve roots and ganglia; (2) the eighth thoracic nerve roots; and (3) the third lumbar nerve roots. The levels were chosen thus in order that the sections might pass through the largest parts of the cervical and lumbar intumescentiae, and through the smallest region of the thoracic cord.

Sections of the encephalon were made (1) transversely, perpendicular to the base of the brain in front of the infundibulum and behind the optic chiasm, being located accurately by means of the tracts of the thalami; and (2) in the case of the cerebellum, sagittally, through the vermis.

Three ages have been chosen for reproduction, and drawings made with the help of a camera lucida. The magnification of the half tones of the cord is 21¾ diameters; of the encephalon, 9½ diameters.

I. Description of Transverse Sections Through the Medulla Spinalis of the Guinea Pig at Birth.

Cervical Level.

A section through the cervical level at birth is reproduced in fig. 1, plate V. Reference to this figure will show that at birth a large number of fibers are medullated, and that the whole area of the white substance is almost uniform in its coloration. The gray substance is traversed by a large number of medullated fibers running in all directions.

The dorsal funiculus is subdivided into the fasciculus cuneatus and fasciculus gracilis, and the latter is again subdivided into two fasciculi by a clearly marked septum. A similar subdivision was found in the medulla spinalis of the white rat.[1] As in the white rat so in the guinea pig the fasciculus is very late in medullating. In the guinea pig this fasciculus presents an area considerably lighter than the substance immediately surrounding it, the medullated fibers in it being both small and comparatively few. In the fasciculus cuneatus a tongue of heavily medullated fibers passes from the level of the tip of the fasciculus gracilis down the septum posterior medianus to the commissura posterior (alba). On either side of the ventral portion of this tongue is a light oval area bounded laterally by the cervix columnae dorsalis, and extending from the commissura posterior to the substantia gelatinosa (fig. 1, plate V). This is the locality of the pyramidal tract.

A third area slightly lighter than the rest of the white substance is to be found in the lateral funiculus just ventro-lateral to the lateral apex of the substantia gelatinosa. Possibly there are in this locality some pyramidal fibers also.

In the cervical cord of the guinea pig at birth there are, then, three light areas: (1) the fasciculus gracilis; (2) the pyramidal area in the fasciculus cuneatus along the boundary of the cervix; and (3) an area containing a few fibers, around the lateral border of the apex of the dorsal column.

In the cervical cord the portion of the white substance immediately surrounding the gray substance is much darker than the white substance at the periphery of the cord, as is indicated in the figures. This appearance is due to two factors, (a) the great number of fibers passing between the ventral columns and the white substance, these fibers seeming to radiate from the ventral columns like spokes from a hub; (b) numerous fibers following the border of the gray substance; e. g., the fibers of the anterior commissure do not all pass directly to the cells of the gray substance, but have to wind in and out about the edge

[1] Animal Education, p. 94.

before they can effect an entrance. A further cause of darkening in the ground bundles around the margin of the gray substance may be that the longitudinal bundles are there more dense. In other words, in the section there may be more transversely cut fibers in the ground bundles than in the peripheral white substance. An enumeration of the fibers shows that in a given area there are in the lateral funiculus 16.7% more cross sections of fibers close to the ventral column than at the periphery. In the ventral funiculus the difference is 20.2% in favor of the given area close to the ventral column as opposed to a peripheral area in the same funiculus.

Thoracic Level.

At the thoracic level the lightly medullated area in the fasciculus cuneatus at the postero-lateral margin of the cervix columnae dorsalis (the pyramidal tract) is less well medullated than in the cervical region. It extends further toward the median line, so that in its ventral half it approaches nearer the median septum and extends ventrally as far as the commissura posterior.

The light area ventral to the lateral tip of the substantia gelatinosa appears in the thoracic segments. The fasciculus gracilis shows the two subdivisions commented upon in the description of the cervical level, the dorso-medial being the less well medullated.

In the thoracic as in the cervical cord the number of medullated fibers in the gray substance is worthy of attention.

Lumbar Level.

The light area in the funiculus cuneatus of the lumbar level occupies a position corresponding to that noticed in the section of the cervical, i. e., an oval area following the border of the cervix of the dorsal column, from the edge of the substantia gelatinosa to the commissura posterior, but separated from the latter by a well marked area of medullated fibers. This area is somewhat smaller than the corresponding area in the cervical, and contains a larger number of scattered medullated fibers than appear at the levels above it.

The light area ventral to the lateral tip of the substantia gelatinosa is present in the lumbar region, and corresponds to the similar area of the higher levels.

At the lumbar level the fasciculus gracilis does not appear in the section, and the funiculi dorsales are depressed below the level of the dorsal column on either side.

In all levels of the spinal cord there is a large amount of medullation, numerous well medullated fibers of all classes being present. Throughout the gray substance everywhere there are fibers passing in every direction, both large and small, separate and grouped into heavy bundles. Commissural fibers cross the median line on both sides of the canalis centralis, the most conspicuous commissure being the anterior. Here fibers running in the plane of the section are extremely abundant. They pass among many cross sections of fibers. Two bundles are enclosed by these commissural fibers (fig. 3, plate V, *y*), and are to be found in this position at all levels and in all individuals examined.

Small bundles of fine fibers are seen passing longitudinally at the junction of the cervix and caput of the dorsal column (fig. 1, Plate V, *x*). They constitute a part of a very extensive reticular formation which in this region passes through one-half or two-thirds of the cervix. The processus reticularis is well marked in the lateral region of the gray substance at every level.

1. In summarizing the appearances in the medulla spinalis of the guinea pig at birth emphasis is to be laid upon (1) the three partially medullated areas in the cervical and thoracic levels, to be found (a) in the fasciculus gracilis, (b) at the ventral border of the fasciculus cuneatus (the pyramidal tract), and (c) at the ventral margin of the apex of the dorsal column; (2) the two partially medullated areas in the lumbar cord, (a) the pyramidal tract which is less well marked than at higher levels, and (b) the area ventro-lateral to the substantia gelatinosa. The fasciculus gracilis is not present in the lumbar cord.

2. In transverse sections the peripheral third of the white substance does not appear to contain so many medullated fibers

as are to be found near the margins of the ventral columns.

3. At all levels there are many medullated fibers passing in every direction throughout the gray substance.

II. Development of the Medulla Spinalis from Birth to Maturity.

Cervical Level.

Between birth and the third or fourth days the formation of medullary substance in the medulla spinalis is apparently at a standstill. After the third day the light areas which have just been described, show a rapid darkening, so that before the eleventh day the medullation of the whole section has become practically uniform, the light areas being closely packed with medullated fibers. These fibers appear to have a smaller average diameter than the fibers of the neighboring funiculi, but their number is sufficient to render these areas as dark as those about them. Between eleven and thirty days the only noticeable change, besides increase in the area of the whole transverse section, is the still further darkening of the areas a, b and c.

In order to compare the white rat of thirty-five days with a guinea pig at approximately the same stage of development (thirty days), the transverse sections from the three levels of a thirty-day guinea pig are reproduced (figs. 5, 6, 7, plate V).

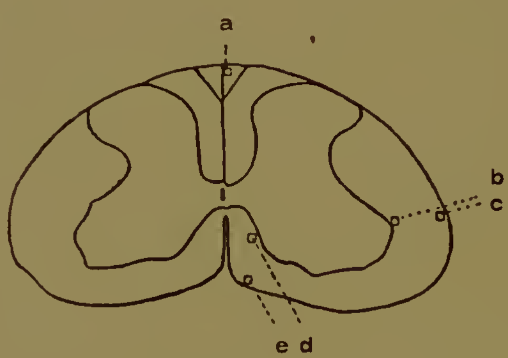
Upon reference to the figure of the cervical level it will be seen that the whole field has become darker than at birth by the great increase in number and in size of medullated fibers. The gray substance is traversed by a relatively larger number of fibers than is present at birth. The drawing of the thirty-day cervical section shows particularly well the cork-screw arrangement of the intra-medullary portion of the fibers passing into the gray substance from the zone of entering roots.

A small light area is to be found in the thirty-day cord also, at the ventro-lateral tip of the substantia gelatinosa. About the tip of the substantia gelatinosa are many fibers running in the plane of the section.

In the cervical cord of the adult (fig. 8, Plate V) the number of medullated fibers is largely increased, the white substance appearing nearly black. Throughout the entire section

the white matter adjacent to the gray appears darker than at the periphery of the section. That this darkening is not due wholly to mere enlargement of fibers already medullated at thirty days is inferred from the presence of small fibers in all parts of the cord.

In order to determine in how far new medullated fibers were responsible for these appearances a tentative enumeration of the fibers in several areas of the cervical cord was made. The areas chosen are represented diagrammatically in text-figure 11 below.



Text-figure 11.

Diagram of the cervical cord indicating the areas in which an enumeration of fibers was made.

In comparing the enumeration of these fibers in the adult with an enumeration in similar regions of the young at birth we find that in the adult there has been both a slight increase in the number of fibers and a considerable increase in their average diameter. The following table presents evidence of increase in number of fibers in the given areas between birth and maturity. The standard area within which the fibers were counted contained .00366 sq. mm., i. e., it was .06048 mm. on a side.

Table Showing Number of Fibers in Given Areas of the Cervical Cord at Birth and at Maturity.

	Dorsal funiculus.	Lateral fun.	Ventral fun.
At birth,	301	215.5 [2]	218 [2]
Adult,	408	203 [2]	246 [2]

[2] Average of enumeration at periphery and at margin of ventral column.

It will be seen that the total increase in number of fibers, all the funiculi being considered together, is 16.81%. The increase in number of fibers, then, can only partially account for the enlargement of the cord during this period.

In the adult the fasciculus gracilis is notably darker than the adjacent areas, whereas it was previously somewhat lighter. Similarly there is a corresponding darkening in the pyramidal area. The areas have been darkening by a great increase in number of medullated fibers. A count of the fibers in a given area of the fasciculus gracilis of both the adult and newborn shows that there has been an increase of 35.5% of medullated fibers in the older animal. In the newborn many fibers were too small to contribute to the darkening of the light areas.

Casual inspection shows that the fibers in the ventral funiculi are much larger than those of the dorsal fasciculi; this leads us to the conclusion that the number of fibers per unit of area is greater in the dorsal funiculus than in the ventral funiculus, and a count proves this to be the case. That is, those regions which show the smallest number of medullated fibers in early life ultimately possess a greater number of fibers than tracts which at that time are practically complete.

In the lateral funiculus there are somewhat fewer cross sections of fibers at the periphery than in the ground bundle near the ventral column, the ratio being 1:1.22. In the ventral funiculus it is found, likewise, that at the periphery there are fewer fibers than near the ventral column, the ratio being here 1:1.69. In both the lateral and the ventral funiculi the fibers at the periphery are larger than those near the gray substance.

Thoracic Level.

Little if any change occurs in the thoracic cord before the fourth day, as was found to be true also in the case of the cervical. The section at the sixth day shows much greater uniformity of medullation, and at eleven days the pyramidal tract can not be distinguished from the neighboring white substance. At eleven days also the fasciculus gracilis is becoming darker than the surrounding regions. In the fasciculus gracilis at

thirty days the medullation is much heavier, and in the adult it appears as dark as the corresponding area at the cervical level.

As at the cervical level, the white matter is darker at the border of the gray substance than at the periphery.

Lumbar Level.

The light area noted in the fasciculus cuneatus of the lumbar level does not disappear quite so completely as the corresponding areas of the more cephalic levels of the cord. By the sixth day the medio-ventral part has become evenly medullated, but at the eleventh day there is still an area in which there has been little or no increase in medullation. Notwithstanding the fact that in the lumbar level this light area was at birth very faintly marked, a suggestion of it persists here longer than in the levels above. Even at thirty days it is not quite lost in the general increase of medullary substance.

The fasciculus gracilis does not appear in the lumbar cord of thirty days, the dorsal funiculi being depressed in such a way as to form a groove at this region. Numerous fibers in the entering root zone and in the fasciculus cuneatus have made this groove relatively less deep than at birth. At maturity this depression can still be detected ; and the fasciculus gracilis, though comparatively very small, appears at this level.

In the lumbar cord the crowding of the fibers in the ground bundle of the lateral and the ventral funiculi is not so conspicuous as it has been higher up. Fibers radiating from the ventral columns appear to be quite as numerous, but the longitudinally coursing fibers are probably not so numerous.

Summary of Changes in Medullation of the Medulla Spinalis Between Birth and Maturity.

1. In the cervical and thoracic levels three areas in the white substance are at birth noticeably lacking in medullated fibers :

a) the fasciculus gracilis,
b) the pyramidal area in the fasciculus cuneatus,
c) in the lateral funiculus an ill-defined area ventro-lateral to the substantia gelatinosa.

2. Before eleven days the first two areas are medullated uniformly with the surrounding regions. The area in the lateral funiculus has received many new fibers and can be distinguished only as a narrow light zone bordering upon the lateral apex of the substantia gelatinosa.

3. By thirty days the two areas in the dorsal funiculus just distinguished as medullating late have become darker than the surrounding region. In the adult these areas are relatively still darker than at thirty days.

4. In the adult the light area in the lateral funiculus still has small fibers, many of which pass longitudinally within the limits of the substantia gelatinosa itself.

5. Since the lumbar level at birth does not possess a fasculus gracilis it lacks one light area mentioned for the levels above. The other two light areas are present, though less well marked than at the higher levels.

6. The ventral half of the pyramidal area soon becomes well medullated, but its dorsal half remains poorly medullated for a longer time than at the higher levels, since even at thirty days it is still a little lighter than the adjacent white substance.

7. On the whole the cord of the guinea pig at birth is very well medullated in all its regions.

Increase in Area of Cross Sections of the Medulla Spinalis from Birth to Maturity.

The changes in the spinal cord which have been described above are such as are apparent by inspection of the various funiculi represented in the drawings. Contemporaneous with the darkening of the section by the increase in the size and the number of medullated fibers there has been an enlargement of the total area of the cord.

A selection of typical sections was made, and their transverse areas ascertained with the planimeter. The results are indicated in the following table :

TABLE I.

Table showing the increase in area of cross sections of the spinal cord of the guinea pig from birth to maturity.

Weight, grms.	Age.	Level,	Substance. White,	Gray,	Total.
108	birth	Cerv.	2.88 sq. mm.	2.34 sq. mm.	5.22 sq. mm.
		Thor.	1.75	.84	2.59
		Lumb.	1.42	1.38	2.80
106	3 days	Cerv.	2.90	2.47	5.37
		Thor.	1.34	.85	2.19
		Lumb.	2.01	2.02	4.03
250.41	30 days	Cerv.	3.67	2.16	5.83
		Thor.	2.21	.93	3.14
		Lumb.	3.12	2.93	6.05
617.9	adult	Cerv.	6.90	2.69	9.68
		Thor.	4.76	.94	5.70
		Lumb.	5.80	3.07	8.87

The percentage increase in the white and gray substances and in the total area of the cross sections in the entire cord is graphically shown in the following table:

TABLE II.

The percentage increase in cross sections of the white substance from birth to maturity.

Age	Cerv.	Thor.	Lumb.
Birth	100	100	100
Adult	138.81	172	308.4

The percentage increase in cross sections of the gray substance from birth to maturity.

Age	Cerv.	Thor.	Lumb.
Birth	100	100	100
Adult	14.9	11.0	122.9

The percentage increase in total area of cross sections of the cord from birth to maturity.

Age	Cerv.	Thor.	Lumb.
Birth	100	100	100
3 days	2.8	15	43.9
30 days	11.6	21.2	116.0
Adult	85.4	120.08	216.78

It will be seen that the percentage increase in both the gray and white substance is much greater at the lumbar level than at the levels above, the lumbar cord, therefore, showing the greatest amount of developmental change from birth to maturity.

The progress of medullation in the thirty day guinea pig has attained about the stage reached by a thirty-five day white rat. The table below compares the areas of the spinal cords of the two animals.

TABLE III.

Table showing the areas of the cross sections of the spinal cords of a guinea pig thirty days old, and of a white rat thirty-five days old.

Animal,	Age,	Level,	White,	Gray,	Total.
Guinea	30 days	Cerv.	3.67	2.16	5.83
pig		Thor.	2.21	.93	3.14
		Lumb.	3.12	2.93	6.05
White	35 days	Cerv.	3.83	3.67	7.50
rat		Thor.	2.08	1.18	3.26
		Lumb.	2.41	4.07	6.48

It will be seen that the absolute areas are closely comparable, the cervical cord of the white rat being, however, larger than that of the guinea pig; so that in volume of the spinal cord as well as in the stage of medullation the guinea pig of thirty days may be compared with the white rat of thirty-five days.

To repeat what has been said before, by way of summary, the spinal cord of the guinea pig increases in area by the development of new fibers, and by the growth of fibers already formed at birth. When we see how heavily medullated the adult cord is, and know how much it has increased in area we conclude that there has been a very great addition of substance by both of these methods.

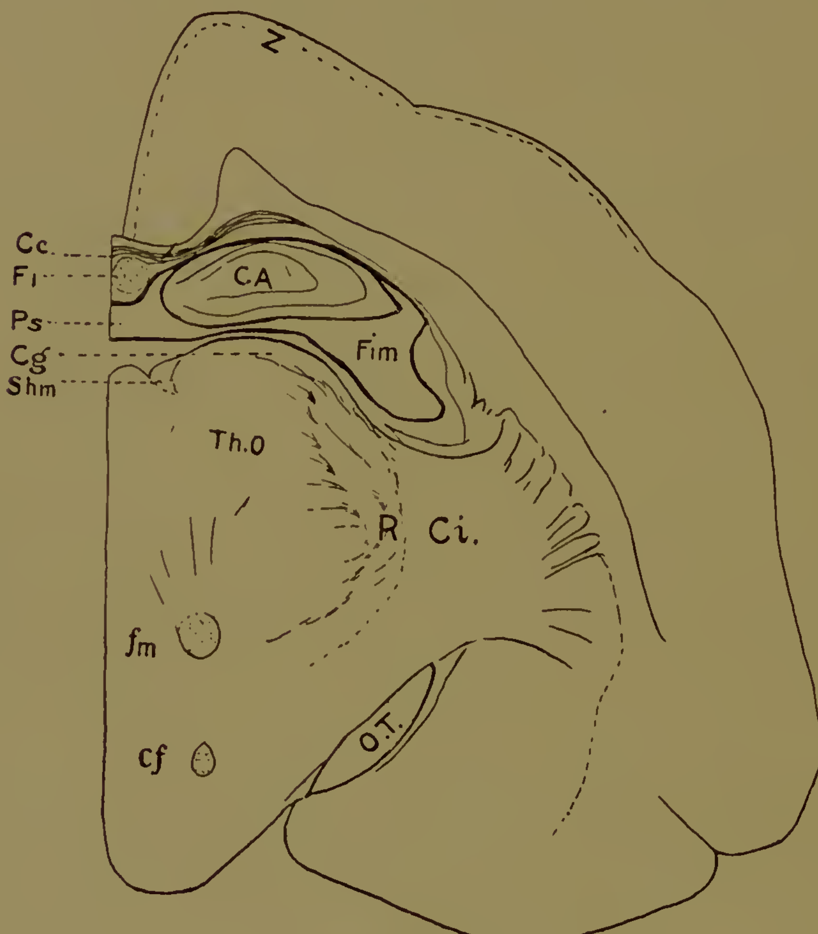
III. The Encephalon of the Guinea Pig.

Cerebrum.

In the encephalon at different ages the relation of the parts is not the same, so that it is impossible to get exactly comparable sections, and structures in the optic thalami were chosen

as being the most reliable marks for the determination of similar levels.

At birth the cerebral hemispheres show many well-medullated tracts. The section reproduced in figure 14, plate VI, is through the cornu Ammonis, ventral to which lie the thalamic structures. An outline drawing has been introduced (Text-



Text-figure 12.

fig. 12) as a key to the representations of the sections of the cerebral hemisphere. The letters in parenthesis refer to corresponding figures in the diagram.

In the diencephalon the thalamus opticus (*Th. o*) with fibers (Radiatio lateralis thalami, *R*) radiating into the internal capsule (Capsula interna, *Ci*); the fasciculus of Vicq d'Azyr (fasciculus thalamo-mammillaris, *Fm*); the Columna fornicis (*Cf*);

and the lateral geniculate body (Corpus geniculatum laterale, *Cg*) appear as prominent features. The principal fiber tracts are already medullated.

As in other rodents in which the olfactory apparatus is well developed, the Ammon's horn (Cornu Ammonis, *CA*) is a conspicuous structure. In the guinea pig at birth the fibers of the Ammon's horn have only begun to be medullated in delicate layers separated by large areas of cells and unmedullated fibers. At the tip of the Ammon's horn the fimbria is already darkly medullated. Dorsal to the Psalterium (*Ps*) and immediately ventral to the Corpus callosum (*Cc*) is seen a group of fibers belonging to the Fornix longus (*F l*).

Extending from near the median line dorsal to the fornix around the cortex and ventro-lateral to the lenticular nuclei is a dark mass of fibers, the white substance of the hemispheres, from which already numerous radial bundles emerge, passing in the direction of the cortical cells.

Not only are fibers to be seen radiating toward the surface, but also there are many fibers in the deeper portions of the cortex running parallel to the cortical surface. By using a high power very fine fibers are visible in the zonal layer (*Z*). But with this magnification no fibers are to be seen at the margin of the cortex. In the white rat this system of fibers does not begin to medullate until after the forty-second day.

Development of the Cerebral Hemispheres.

The drawings of the encephalon at thirty days and at maturity show a gradual increase in number and complexity of pathways formed by medullated fibers. The most remarkable changes have been in the Ammon's horn (*CA*), in the Psalterium (*Ps*), in the internal capsule (*Ci*), and in the white substance of the hemispheres. The optic tract appears well medullated. The bundles of fibers radiating toward the cortical surface from the white substance of the hemisphere become more abundant between birth and maturity, and extend further toward the surface. The fibers of the stratum zonale become more evident and the layer becomes thicker. In general, there-

fore, the tracts of medullated fibers become more densely medullated in the older animals.

The area of the cross section of the encephalon has increased in size, and incipient sulci are distinctly more marked in the adult than in the newborn brain. At the temporal margin of the cortex a sulcus, scarcely indicated at birth, has become well marked in the course of development. The increase in size of the temporal lobe seems, as indicated in the drawings, not to have been a progressively symmetrical growth; up to thirty days the ventral portion has developed most, after that the ventro-lateral portion undergoes the greatest change.

Cerebellum.

The sections from which the drawings were made were taken in the median sagittal plane, passing therefore through the vermis. The changes in this part of the encephalon are readily appreciated from comparison of the drawings.

As to general contour, it will be seen that the folia are numerous at birth, and in the course of development become larger and more pronounced. The PURKINJE cell layer is marked in the drawings by a white line (the cells not staining by this method) separating the molecular and granular layers.

At birth the molecular layer is free from medullated fibers. The granular layer contains fibers radiating from the white laminae; these fibers are especially numerous at the apex of the laminae. In the granular layer very many fibers are seen running more or less parallel to the white laminae. Further out in the granular layer such fibers are shorter and finer. Almost all the fibers seem to be medullated in the white laminae even at birth, and are densely packed together.

There is a great increase in the number of fibers found in the granular layer from birth to maturity. Such an increase is particularly marked in the fibers at the junction of the laminae and granular layer. It can be seen that the folia, present at birth and reaching the surface of the vermis, tend to divide as the animal becomes older, and that the folia deep-seated at birth push their way towards the surface.

The changes in the encephalon between birth and maturity as exhibited in the figures may be recapitulated as follows:

I. At birth no important cerebral pathways are unmedullated.

II. The number of fibers increases very greatly up to maturity.

III. The Ammon's horn corresponds in its development to the cortex, and at birth has very few medullated fibers.

IV. Few tangential fibers of the zonal layer are present at birth, and at no time are such fibers numerous in the stratum zonale of the guinea pig.

Increase in Area of Cross Sections of the Encephalon.

There are no observations showing the increase in weight of the encephalon of guinea pigs between birth and maturity. Linear measurements, however, show clearly that during this period the encephalon increases in size as well as in number of fibers.

The area of the cross sections used for illustration, of both cerebrum and cerebellum was measured, and is presented in the following table:

TABLE IV.

Table showing the increase in area of cross sections of the encephalon between birth and maturity.

Age,	One cerebral hemisphere,	Cerebellum (mesial section of vermis).
Birth	60.73	30.89
30 days	73.52	45.29
Adult	83.05	58.70

TABLE V.

Table showing percentage increase in area of cross sections of encephalon between birth and maturity.

Age,	Cerebral hemisphere,	Cerebellum.
Birth	100	100
30 days	21.06	45.15
Adult	36.77	90.03

IV. Comparison Between the Nervous System of the Guinea Pig and that of the White Rat.

At the end of the study upon the psychical processes of the guinea pig a comparison is made between the psychical and physical development of the guinea pig and the white rat. It was found that the white rat is born extremely helpless and undeveloped, whereas the guinea pig is independent and well developed. On the psychical side the guinea pig has reached the limit of his possibilities by the third day, while the white rat reaches psychical maturity from twenty-three to twenty-seven days. It was suggested that the contrast between the nervous systems of the guinea pig and of the white rat might be analogous to the contrast in their physical and psychical development.

We have seen in detail what is the condition of the guinea pig's nervous system at birth, and what changes occur during progress to maturity.

A description of the same cycle for the white rat will be found in Animal Education, pp. 87-111. Summarizing these results we find that in the white rat there are no medullated fibers present at birth; that in the spinal cord certain tracts (pyramidal tracts, fasciculus gracilis, etc.) medullate slowly, and that even in the adult the pyramidal tracts do not stain completely; that development in the cerebellum is more rapid than in the cerebrum; that medullation in many regions of the cerebrum is very slow up to the twenty-fourth day, after which the fibers rapidly mature.

Now, if we compare the sections of the guinea pig's spinal cord with sections of the white rat's spinal cord we see that the guinea pig at birth has reached the same stage of development attained by the white rat at twenty-four days. Similarity between the new-born guinea pig's psychical processes and those of the twenty-four day white rat is correlated with surprising accuracy with the similarity in their nervous systems. The similarity is present in a less marked degree between the cerebral

cortices owing to the fact that medullation in the guinea pig appears to be more advanced.

Very little change occurs in the central nervous system during the first three days of the guinea pig's life. Medullation then increases quite steadily but slowly as compared with the white rat. When the white rat is thirty-five days old it has a neural development at the same stage as the thirty day guinea pig.

Our conclusion then is that the guinea pig is psychically mature soon after birth, and at that time has a well medullated nervous system; furthermore, the degree of development of the nervous system corresponds to that of the white rat at 23-27 days, or its period of psychical maturity.

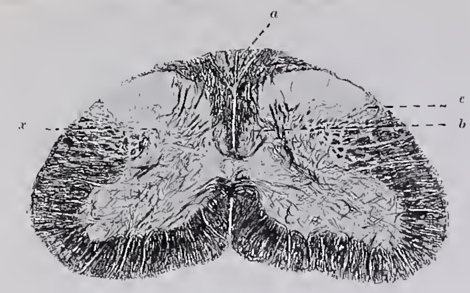


Fig. 1. Cervical Cord. At birth

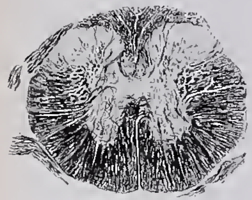


Fig. 2. Thoracic Cord. At birth.

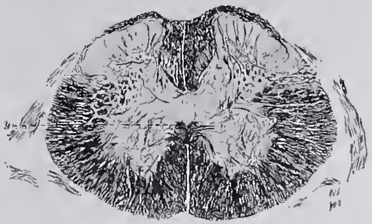


Fig. 3. Lumbar Cord. At birth.

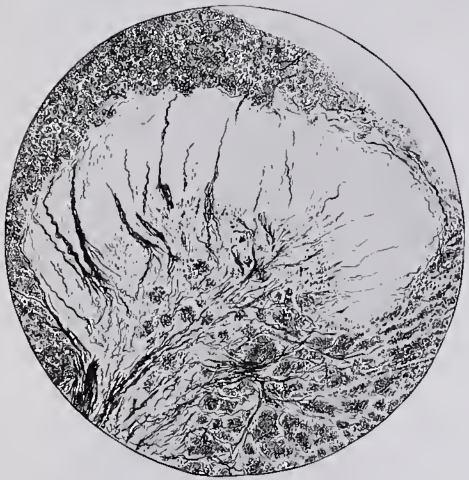


Fig. 4. Dorsal Column of Thoracic Cord. Thirty days.

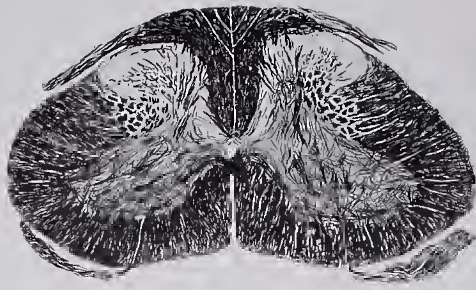


Fig. 5. Cervical Cord. Thirty Days.

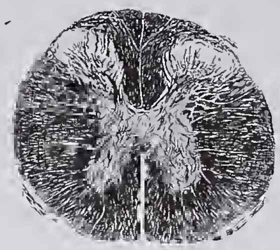


Fig. 6. Thoracic Cord. Thirty Days.

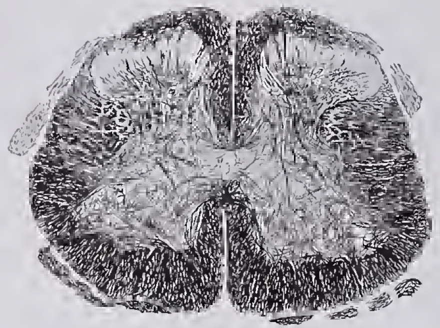


Fig. 7. Lumbar Cord. Thirty Days.

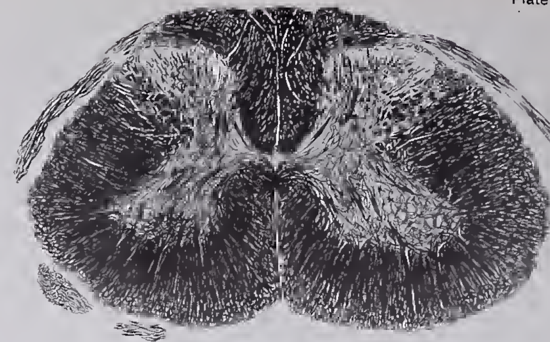


Fig. 8. Cervical Cord. Adult.

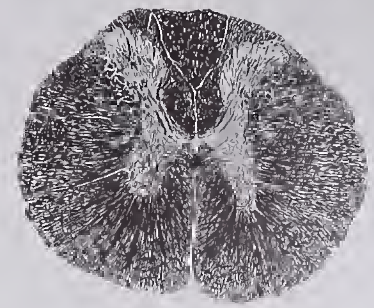


Fig. 9. Thoracic Cord. Adult.

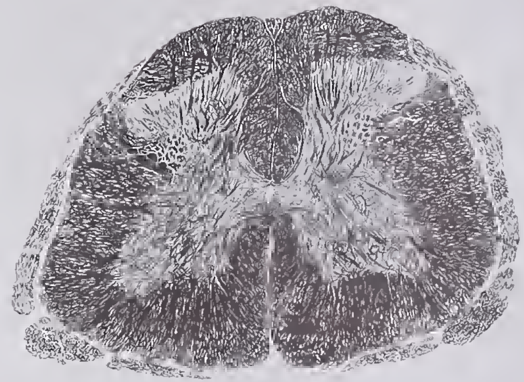


Fig. 10. Lumbar Cord. Adult.

Fig. 11. Vermis of Cerebellum. At birth.

Fig. 12. Vermis of Cerebellum. Thirty days.

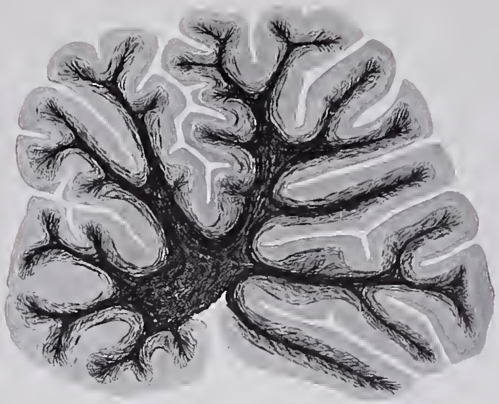


Fig. 13 Vermis of Cerebellum. Adult.

Fig. 14. Cerebral Hemisphere. At birth.

Fig. 15. Cerebral Hemisphere. Thirty days.

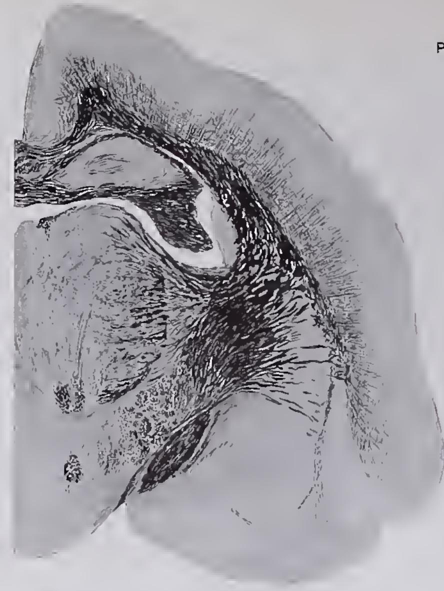


Fig. 16. Cerebral Hemisphere. Adult.